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Hawaiian Archipelago Marine Ecosystem Research (HAMER)

Hawaii Division of Aquatic Resources
Papahānaumokuākea Marine National Monument
NOAA Pacific Islands Fisheries Science Center
University of Hawaii
U.S. Fish and Wildlife Service
Western Pacific Regional Fishery Management Council

Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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HAWAIIAN ARCHIPELAGO
MARINE ECOSYSTEM RESEARCH
(HAMER)

Vision Statement:

Achieve sustainable conservation and management throughout Hawaii's marine ecosystem through improved understanding of the unique physical and biological attributes of the Hawaiian archipelagic marine ecosystem, their interconnected dynamics, and their interactions with human beings.

Objective:

To have Hawaii serve as a large-scale archipelagic laboratory for the investigation of biophysical processes, comparing the protected and nearly pristine Northwestern Hawaiian Islands to the heavily used main Hawaiian Islands to improve resource management within Hawaii and in comparable marine ecosystems worldwide.

HAMER will:

- **Fill critical and important research gaps in the underlying science of marine ecosystem dynamics.**
- **Complement national, international, and state ecosystem research initiatives.**
- **Improve understanding of the behavior of humans in a marine ecosystem approach to conservation and management.**
- **Formulate predictive theory of ecosystem dynamics relative to physical and biological variables.**
- **Generate useful information for conservation managers.**

EXECUTIVE SUMMARY

The Hawaiian Archipelago Marine Ecosystem Research (HAMER) plan is a conceptual layout of a place-based, 10-year, ecosystem research initiative dedicated to understanding broad-scale archipelagic ecosystem processes. The plan was drafted by a multiagency team guided by managers of Federal, State and University institutions that conduct research in Hawaii. The plan identifies six research themes important to management including:

(1) ecosystem indicators and metrics
(2) native biodiversity and invasive species
(3) connectivity
(4) human interactions
(5) resilience and recovery
(6) modeling and forecasting.

Working groups of regional scientists provided examples of the types of research to be conducted. The indicator and metrics research will include physical/chemical monitoring, assessment of habitat change, fish assemblage composition, and links to remote sensing. The biodiversity research includes inventory, life history, invasive species, and the ecosystem effect of removals. The connectivity studies include assessment of hydrodynamics, movement of animals, population genetics, and transport modeling. Human interaction research includes studies on seafood safety, catch and release fishing, implementing restoration efforts and retrospective social analyses. The resilience and recovery theme will discern between natural and anthropogenic disturbance, examine effects of fishing on resilience, and assess the influences of environment and energy flow. Finally the modeling and forecasting theme will integrate data on mapping and community structure with quality control screening to generate prediction scenarios for future evaluation. HAMER is strategic research envisioned to rapidly advance ecosystem science management through the year 2020. Periodic symposia and independent reviews are planned to be an integral part of the evaluation of HAMER's progress in achieving the 2020 mile post. HAMER does not recommend an institutional structure for undertaking the research – it focuses on the conceptual basis for developing detailed research initiatives within the context of single and multiagency funding opportunities.

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INTRODUCTION

The Hawaiian Archipelago Marine Ecosystem Research (HAMER) plan describes a 10-year, multiagency, collaborative program proposed to advance ecosystem science and resource management in Hawaii. This program will coordinate existing research efforts but will also require significant increase of current budgets to meet the goals and objectives of this plan.

The Hawaiian Archipelago is an exceptional part of the world and as such it can serve as a natural laboratory. Its geography makes it uniquely situated to address emerging ecosystem issues that are relevant internationally. Its 2500-km expanse is unified by its geological origin and geographic isolation. This vast expanse is subject to great spatial gradients in oceanography, erosion, and geomorphology. Because of its remote nature, the Hawaiian marine ecosystem has some of the highest marine endemism on earth with many species unique to the archipelago. Over the past 2 millenia, humans have settled and altered the archipelago with the southern one-fifth currently subject to use by 1.4 million residents and their associated anthropogenic stressors. The northern four-fifths of the archipelago are generally uninhabited but not absent of historical or current stressors. The entire archipelago thus reflects a combination of geologic processes coupled with an associated marine ecosystem succession, including substantial speciation in isolation of neighboring ecosystems. Add to this the comparatively recent occupation of the main Hawaiian Islands (MHI) by human beings and you have in effect a natural laboratory where one portion is subject to anthropogenic influences and the rest is relatively pristine. This affords a unique opportunity to discern the human influence in the marine ecosystem across the archipelago. Few regions on the planet have the isolation, spatial structure, endemism, and research history that are needed to evaluate ecosystem dynamics and function at this scale. This unique situation calls for a collaborative research approach designed to advance ecosystem science, develop new technologies, and assist society in making the most of its attributes while preserving them for future generations.

This document identifies the key research themes and priorities needed to advance ecosystem science and assist natural resource agencies in Hawaii with their mandates. Expected products include identifying ecologically relevant boundaries, characterizing biodiversity, understanding the impacts of purposive extraction, and identifying predator-prey linkages as components in ecosystem models. Expected benefits include identifying ecologically safe harvest and use levels, making estimates of carrying capacity, improved ability to react to locally catastrophic events (e.g., hurricanes or marine pollution), and the design of alternative conservation and management schemes.

Over the past decade, there has been a paradigm shift towards the idea of ecosystem-based resource management, which has been incorporated into NOAA's mission statement, namely "to protect, restore and manage the use of coastal and ocean resources through ecosystem-based management." In parallel with this management, agencies such as the Western Pacific Regional Fishery Management Council (WPRFMC) have moved from single species to ecosystem-based management through the development of archipelagic Fishery Ecosystem Plans for Hawaii and U.S. flag Pacific Islands in the western and central Pacific. These plans will benefit from many of the research activities outlined in the HAMER. The plan is a departure from single-species and specific habitat research approaches and will address ecosystem questions to benefit natural resource management in Hawaii and elsewhere. This plan does not replace the statutory authority of any of the management organizations in Hawaii (Federal, State, County or other) and it is understood that research at this scale will involve increased coordination amongst the various jurisdictions involved in these marine and coastal areas.

The results of this research will be used to identify and implement conservation and management actions that will include maintaining ecosystem function, applying an ecosystem context to fisheries and implementing the recovery of protected species. The first beneficiary will be the main Hawaiian Islands where a broad range of anthropogenic stressors burden the ecosystem.

Examples of questions to be addressed by HAMER

- How does biodiversity contribute to ecosystem services?
- What is the role of endemism in the evolutionary process?
- Why are monk seals healthier in the intensively fished MHI?
- What is ecosystem function with fishing control versus open access?
- Do intact marine habitat and its attendant biota protect terrestrial Hawaii from disasters?
- How are the Northwestern Hawaiian Islands connected biologically to the main Hawaiian Islands?
- How can human activities be mediated to achieve a sustainable ecosystem?

BACKGROUND

In November 2004, the 3rd Northwestern Hawaiian Island Symposium was held in Honolulu, Hawaii, to bring together researchers who had conducted research in the Northwestern Hawaiian Islands (NWHI). It was the first such meeting in more than 20 years[1]. A consistent theme at the symposium was the need for a coordinated research effort that encompassed both the NWHI and the MHI to identify the workings of an archipelagic system. A similar conclusion was reached at a 2005 Ecosystem Science and Management workshop hosted by the WPRFMC[2]. This interest in a collaborative program is the result of emerging public desire for comprehensive research and monitoring programs. To achieve this,

[1] Northwestern Hawaiian Islands, 3rd Scientific Symposium. Atoll Research Bulletin Vol 543; 579 p.
[2] WPRFMC (Western Pacific Regional Fishery Management Council). 2006. Ecosystem Science and Management Planning Workshop: Development of Ecosystem-based Approaches to Marine Resource Management in the Western Pacific Region. Workshop Proceedings. July 18, 2006. Honolulu, Hawaii. 157 p.

substantial improvements in capabilities for conducting research on an ecosystem scale are needed. These drivers result from an increasing emphasis within agencies to use ecosystem-based approaches to resource management. Despite decades of study focused on fisheries and protected species, there has been no research initiative to define the structure and function of Hawaii's large marine ecosystems. The closest program to this objective has been the recent national coral reef ecosystem initiative which has focused on the ecological aspects of the shallow coral reefs. The HAMER was proposed to expand research across ecological subsystems of the archipelago and expedite the shift to ecosystem management to one that emphasizes sustainability and protection of ecosystems and biodiversity.

In January 2005, a steering committee was formed to initiate the process by which the HAMER would be assembled and to ensure that managers from marine resources agencies were involved. There followed a series of meetings with managers and researchers to define the basic scope of the plan, followed by several months of work by a smaller drafting team before the draft plan was taken back to the managers for comment in December 2006. The draft plan — focusing on the vision, objectives, and scope of activities — was then wrapped up by the management team in early 2007. The plan was independently reviewed by a national panel of ecosystem experts that met in Honolulu in August 2007. The panel's comments on the plan are included later in this document.

SCOPE OF ACTIVITIES

This research program will provide the underlying basis for projects that have potential to advance ecosystem science and improve resource management on an ecosystem scale. The program is not a platform for esoteric research. The program will focus on the Hawaiian Archipelago but will recognize the interconnectedness among the marine habitat of Hawaii, Hawaii's terrestrial ecosystems, and adjacent water masses and insular ecosystems of other archipelagos. The emphasis will be primarily biophysical with select social science elements incorporated to maximize applicability to resource management. All physical and taxonomic components of the marine ecosystem are candidates for study as long as they address the research themes and guiding principles identified in this plan. This program is envisioned to fill important research gaps and complement state, national, and international ecosystem research initiatives. Appendix 3 addresses the HAMER focus in relation to other applicable ecosystem plans.

RESEARCH THEMES

The HAMER plan was developed within the context of a number of existing research plans and guidelines from Hawaii and elsewhere with a view to proposing some broad research themes. Several planning documents were reviewed, including:

- State of Hawaii Research Priorities (2002–2004)
- The National Coral Reef Plan (2002)
- Research priorities of the Great Barrier Reef Marine Park Authority (1994)
- NOAA Workshop on Ecosystem-Based Decision support tools for Fisheries (2005)
- National Marine Sanctuaries Division (2004)

The review revealed some gaps in the region's ecosystem research and identified some areas that required greater integration and synthesis across subdisciplines. Six research themes of importance across agencies were identified as relevant to current and anticipated future management needs in Hawaii. All of these themes integrate physical, biological and social components to address ecosystem processes.

Research Theme	Physical	Biological	Social
Ecosystem indicators and metrics	X	X	X
Biodiversity and invasive species		X	X
Connectivity	X	X	
Human interactions		X	X
Sustainability, resilience, and recovery		X	X
Modeling and forecasting	X	X	X

Ecosystem Indicators and Metrics

Long-term ecosystem monitoring requires an agreed-upon suite of metrics and parameters that are understood and used by the management agencies. This theme will develop the practical and theoretical bases for monitoring. Implicit in this research will be a focus on progressively shifting the data stream from one tier to the next, sampling adaptively, and improving the interpretative power of the indicators.

Native Biodiversity and Invasive Species

Ecosystem function is the product of competition among species in the biological community. The functions and roles of species in ecosystems, e.g., in maintaining ecosystem stability, are poorly understood. The role of some species is more conspicuous than others. Because we are uncertain how the ecosystem as a whole works, safeguarding biodiversity is one strategy to help sustain ecosystem function. Impacts on biodiversity from extraction and colonization by alien species must be understood. Research on this theme will include exploration and inventory, life history investigations, and comparison of protected and unprotected native species. Parallel research will document possible ecological changes associated with colonization by invasive species and identify possible measures to prevent or mitigate their spread.

Connectivity

The appropriate scale at which to monitor and manage ecosystems needs to be clearly understood. This requires an understanding of spatial and temporal exchange within physical and biological processes to identify ecological boundaries between subregions and assess the rate and pattern of biodiversity evolution in the archipelago. The research on this theme will focus on physical oceanography and the biological processes that may link one part of the Hawaiian Archipelago to another.

Human Interactions

Understanding the sources, types, and magnitude of human interactions with the physical and biological components of Hawaii's marine ecosystem is essential to improving marine resource management. Currently, many of our interactions with Hawaii's marine ecosystem are undocumented and their impacts are poorly understood. This information gap seriously undermines efforts to discern between natural and anthropogenic effects. A full understanding of the impacts of human activities (both land-based and at-sea) on Hawaii's marine ecosystem is also essential for realistic ecosystem science and modeling. Research on this theme will focus on the motivations and behaviors of people as individuals and communities in relationship to the marine environment as well as on the relationship between conservation and management policies and society.

Resilience and Recovery

Understanding resilience and recovery processes requires a heightened level of sophistication in ecological understanding. Insight is needed on the various pathways and modifiers to ecosystem resilience. Inherent in this will be an ability to follow "trade-offs" in multiple impacts and in multiple time scales and perhaps develop a common currency (e.g., energy units) for future analyses. This theme will tie together basic biophysical studies with broader ecosystem modeling.

Modeling and Forecasting

Estimates of carrying capacity are a critical requirement for management and long-term planning. The process by which such estimates are derived, the scale employed, and how much the process varies over time will influence the interpretation of ecological indicators. Research on this theme will attempt to estimate carrying capacity and forecast change using the indices and metrics identified in the earlier theme with the goal of advancing ecosystem science and management.

RESEARCH PRINCIPLES

The research program will prioritize research for relevance to major management and conservation challenges in the archipelago, and adhere to **five guiding principles**:

(1) *Select testable hypotheses that are consistent with the vision statement.*

The range of potential approaches needs to be critically reviewed to identify the most promising and expedient means to advance archipelagic ecosystem research.

(2) *Understand physical, biological, and related social processes at an archipelagic scale.*

Defining the appropriate scale at which to measure and monitor the ecosystem requires an understanding of spatial and temporal spectra and the relevant scales of physical, biological and social elements and processes. Such understanding will help to identify ecological boundaries between subregions.

(3) *Conduct research on an archipelagic scale that employs comparisons between the NWHI and the MHI.*

Discerning between natural and anthropogenic effects is inherently difficult. Urbanization, natural variability, fishing, episodic events, and climate change are intertwined, often confounding the analyses. The Hawaiian islands are one of the few places on the planet affording a research venue where a major part of the marine environment has historically been undisturbed and where further anthropogenic influences will be strictly controlled. Hence, science here can be directed at understanding ecosystem variability with the best chance for success. Research that uses the NWHI and MHI in a comparative approach will be an ideal means to understand ecological linkages.

(4) *Acknowledge that any success at long-term sustainable ecosystem management will require understanding the human component.*

There is a need for social research that complements the findings from the biophysical studies. The ability of managers to understand and implement changes based on ecological studies is often thwarted by poor insight about the human constituents who will be affected. A group of studies needs to focus on the benefits and impacts of social change that come with implementing new ecosystem-based management strategies. The findings from this work should include ways to improve societal transitions in resource management. This work is as important as the biophysical and biodiversity elements and needs to be integrated up front and sustained throughout the duration of the research program.

(5) *Conduct research on a scale and intensity sufficient to advance ecological modeling and forecasting.*

Institutions internationally have identified ecosystem science as their priority for research. Ultimately, one goal is to develop understanding and technology that allows us to "ecologically forecast." The objective of ecological forecasts would be to prevent overuse, warn of impending episodic harmful events, and ensure ecological resilience.

RESEARCH THEME PROJECTS

HAMER is envisioned to be a 10-year project beginning in 2010. The years prior to startup are dedicated to preprogram actions to organize and coordinate implementation of the plan. Each of the six research themes presented above provides the basis for a variety of research projects. A series of focus groups was held in April and May 2006 to obtain input on the type and nature of research projects needed to address the identified research themes. A separate focus group was held for each of the six research themes and the participants proposed and prioritized near-term (0–3 yr), intermediate-term (4–7 yr), and far-term (8–10 yr) products that met the objectives of HAMER. Participants selected for the focus groups had a history of research in the theme area (Appendix E). They were provided a short presentation on the nature of HAMER and the reason for the focus group and were then asked to provide their insight in the context of the five guiding principles of the program. Feedback from the focus groups was then entered into matrices and used to write the descriptive sections that follow for each of the six research themes. Key references for each research theme (and other sections of this report) are provided in Appendix F. Example investigations were divided into "mission elements" which are linked with descriptive pages in Appendix G Research missions will start in 2010 and will progress throughout the decade achieving near-, intermediate-, and far-term objectives with periodic reevaluation of progress toward achieving an Archipelagic Goal for Ecosystem (2020 AGE). Periodic symposia will be integral to the HAMER program.

Table 1.--HAMER timeline.

HAMER Timeline						
	Near-term		**Intermediate-term**			**Far-term**
		symposia / review		symposia / review		symposia / review
2008	**2010**	**2012**	**2014**	**2016**	**2018**	**2020 AGE**
Preprogram actions					**Archipelagic Goal for Ecosystem**	

Table 2.--Overview of HAMER research themes by near-, intermediate-, and far-term objectives.

	Research Themes					
	Ecosystem Indicators and Metrics	**Native Biodiversity and Invasive Species**	**Connectivity**	**Human Interactions**	**Resilience and Recovery**	**Modeling and Forecasting**
Overall Strategic Objective	Identify key ecosystem variables for long-term monitoring	Conduct biotic inventory and appraise current/ potential impacts of alien species	Identify subregions & boundaries that are ecologically meaningful	Document spatial/temporal resource use & distinguish anthropogenic changes from natural variability	Understand the capacity and mechanism of resilience in natural systems	Develop models as a means to advance forecasting
Near-term Objectives Years 1-3	Appraise available indices to track oceanography, habitat, and fisheries	Describe taxonomy and biological ecology of native and invasive species	Determine the (presence/absence) connectivity between the NWHI and MHI	Identify undocumented sources of extraction and begin monitoring (e.g., recreational take)	Identify and understand pathways of ecosystem resilience	Conduct gap analysis to determine scale, resolution & variables for modeling. Current compressed models used for predictions
Intermediate-term Objectives Year 4-7	Begin “bridge-type” investigations between indices			Identify other human interactions with the marine ecosystem	Consider naturally occurring modified to ecosystem resilience	Evaluate original model performance & submit revised versions.
Far-term Objectives Years 8-10	Document connections between indices and strive to consolidate to process-based sampling linked to remote sensing	Identify ecological shifts in ecosystems that are a result of invasive species	Identify and document variability of retention and sinks	Discern anthropogenic influences from natural variability	Understand the impacts to resilience from anthropogenic and natural sources	Develop forecasting models and conduct sensitivity analysis

Ecosystem Indicators and Metrics

Research theme: Long-term ecosystem monitoring requires an agreed-upon suite of metrics and parameters that are understood and used by the management agencies. This theme will develop the practical and theoretical bases for such monitoring. Implicit in this research will be a focus on progressively shifting the data stream from one tier to the next, sampling adaptively, and improving the interpretative power of the indicators.

Overview

Long-term ecosystem monitoring is both a research activity and a fundamental management responsibility. Managers must understand how ecosystems have changed to predict their future conditions and needs. The world itself is constantly changing, and the suite of ecosystem indicators must detect changes and trends. As our understanding of ecosystems increases, new parameters, indicators, and technologies emerge to increase the scope, power, predictability, and implications of monitoring. Managers must understand the monitoring program and its future evolution; indicators should include simple metrics that nonscientists can understand. Indicators should be designed to detect changes at useful temporal and spatial resolutions, characterize natural variability, and differentiate between natural and anthropogenic effects where possible.

Resource and logistical limitations, especially within a large archipelago like Hawaii, require ecosystem monitoring to focus on a set of sensitive indicators that collectively serve as the proxy for total ecosystem behavior. The sum of all indicators must reflect the spectrum of ecosystem dynamics and functioning: oceanography, climatology, chemical interactions, biological interactions, population dynamics, habitats, etc. Moreover, the remoteness of the Northwestern Hawaiian Islands from the populated main Hawaiian Islands will require some reliance on remotely-sensed indicators, because the funds for costly ship-based monitoring expeditions and the seasonal windows for safe field monitoring are both limited.

Monitoring itself must be both spatially and temporally rigorous; the former accounting for all “key” parameters, species, and habitats during each sampling event to minimize the confounding effects of temporal variability, and the latter insuring that repetitive surveys are conducted at the same locales to minimize the effects of spatial heterogeneity.

The contrast between the more crowded, overfished, and polluted waters of the MHI vis-à-vis the remote, small and largely uninhabited NWHI provides a unique opportunity for understanding ecosystem change at an archipelagic level. Some of the selected indicators for monitoring this change must have adequate sensitivity to differentiate ecosystem response between the two subregions, ultimately leading to a better understanding of the archipelago’s entire ecosystem.

Research Priorities

Physical and chemical indices--The physical and chemical factors affecting the ecosystem include shifts in carbon dioxide flux, wave regimes, water circulation, storms, thermal expansion, sea level rise attributed to subsidence or melting of polar ice, and other cyclical or decadal phenomena. For example, sea level rise may be eroding the nesting and breeding islands for seabirds, sea turtles, and Hawaiian monk seals. Moreover, the reefs may be subject to increasing rates of carbonate erosion vis-à-vis accretion, resulting in loss of corals, coralline and sand-producing algae, and other reef life, and reduced ecosystem productivity. Hindcasting of these parameters and review of past aerial imagery can indicate possible future trends and enable better estimates of jeopardy to critical islands and shorelines, charismatic megafauna, endangered and threatened species, and reef maintenance and stability. Moreover, subregional comparisons allow us to assess the synergistic effects of anthropogenic stress and latitude.

Biotic indices--Benthic Habitat.--Benthic habitats and organisms, especially on reefs, often display vast inexplicable heterogeneity over small gradients of depth, wave exposure, and sediment cover, even within short horizontal distances on reefs. On one hand, these circumstances require emphasis on stratified habitat sampling rather than random or haphazard selection of monitoring sites. On the other hand, the high cost of ship-based expeditions dictate that site selection and field surveys be accomplished within a time period of 1 or 2 hours. To improve benthic monitoring, habitat mapping and classification or ordination must be accomplished within all depth and habitat ranges and used as the basis for site selection. The benthic monitoring parameters must span the range of benthic response to natural and anthropogenic stresses. The goal of monitoring must include the ability to predict the magnitude of ecosystem change based on the dynamics of each given habitat type, and in turn assist managers in deciding whether mitigation, restoration or other interventions are warranted.

Fishery Dynamics--Recent studies reveal top-down forcing of predators on the indirect control of algae cover via herbivorous fish grazers. Piscivores directly alter herbivore abundance, population size structure, and maturation schedules, while herbivores directly control algal biomass. Matched field experiments in both the MHI and NWHI would contrast the responses of fish structure in areas that are less fished versus areas more heavily fished and be piggybacked as part of other benthic monitoring programs. The research would help to establish ratios of top predators to herbivores, and define an indicator of the degree to which fishing can affect reef resilience. In turn, these findings could help managers develop guidelines for restricting the magnitude of top predator take and special, time-varying restrictions on herbivore take.

A second area of inquiry would be to develop life history demographics and attributes that discern the state of ecosystem and structure of the fish assemblage. These include characterizing the temporal and spatial differences in densities and assemblage structure over several years and using these patterns to assess the impacts of fishing pressure over longer time periods. These metrics would then be scaled and applied to a range of coastal areas with varying degrees of fishery development. Eventually, this research would lead to the ability to predict biomass based on key forcing variables and model the mechanisms that determine reef fish abundance (benthic and water-column primary productivity, oceanic transport of fish larvae, quantity and quality of recruit shelter provided by specific reef habitats, etc.). In turn, this research could help managers develop more proactive and effective fishery regulations.

A third area of inquiry would be to evaluate the sight-ability and behavior of key apex predators in the presence of humans. Some predators, like the giant trevally, are sometimes attracted by or repelled by divers, their behavior conditioned by prior encounters. These behaviors in turn can compromise the value and accuracy of in situ visual surveys. Biomass density would be estimated using multiple techniques at varying spatial scales, including in situ diver, remote video, and conventional tag and recapture. The different results from each of these methods could lead to predictions on the magnitude of the survey bias and ways remove the bias from abundance estimates.

Given the disparities among contemporary survey methods, a logical final area of inquiry would be to explore alternative metrics for fishery target and prey species. Some examples of statistics that could be collected during monitoring surveys and evaluated as metrics are changes in (1) median body length, (2) upper quartile of body size distributions, (3) body size at maturity for key predator and prey species, and (4) size at color (sex) change for parrotfish. These new metrics could then be compared between populations in fished (MHI) and unfished (NWHI) areas within the archipelago and assessed for their sensitivity and ability to indicate change in population or ecosystem status or predict population dynamics. The metrics would also be evaluated to determine if and how changes in body size structure or maturity composition affect management actions, such as decisions on the level of take.

Remote-sensing indices**--**Remote sensing can provide imagery on a range of biophysical phenomena. It can be used to calculate the ratios of sand and algae to reef cover as an indicator of reef health. Data on these ratios would be collected from space on a global basis with the expectation that more stressed reefs would show greater variations. Initial research would focus on the entire Hawaiian Islands archipelago using the same technique (hyperspectral imagery) to see if latitudinal or anthropogenic patterns occur in the expression of the ratio. If fruitful, the NWHI would serve as reference with which other ecosystems could be compared. This approach could track broad changes globally and could also enable comparisons with the signatures of other remotely sensed data projects. Ultimately, the NWHI could serve as an international benchmark for reefs worldwide by distributing up-to-date remote sensing products in a Web-based format to be used as critical metrics of ecosystem dynamics.

Table 3.--Program and priorities for the ecosystem indicators and metrics theme.

Hawaiian Archipelago Indicators and Metrics	Focus Areas	Example Investigations	Mission Elements**	Final Product
Physical and chemical	• Sea level rise • Carbonate production • Carbon dioxide • Aragonite saturation	• Identify loss of NWHI sand islets • Determine if reefs are accreting or in decline • Calculate the role of wave energy in suspending and recycling • ecosystem energy budgets	I-PM[1] I-CM[2]	• Show change in PCO2 on a decadal scale. • Verify latitudinal effect on calcification rates
Biotic	• Appropriate and alternative indices • Biological time series • Trophic structuring	• Review existing indices for efficiency and simplicity. • Identify habitat effects on the biotic community and community effects on habitat • Determine size at sexual maturity/sex change	I-BSA[3] I-BHC[4] I-FAC[5]	• Easily understandable indices for managers. • Process-based sampling versus random stratified sampling
Remote sensing	• Benthic and oceanographic habitat structure and change	• Hyperspectral evaluation of sand-to–hard-bottom ratios • Persistence of oceanic features	I-RS[6]	• International benchmarks for worldwide comparison • Efficient means for monitoring

Notes:

*See Appendix G for mission descriptions
****Mission elements:**
I = Indices
[1]Physical Monitoring
[2]Chemical Monitoring
[3]Biotic Sensitivity Analysis
[4]Benthic habitat change
[5]Fish assemblage composition
[6]Remote sensing

Native Biodiversity and Invasive Species

Research theme: Ecosystem function is the product of competition among species in the biological community. The functions and roles of species in ecosystems, e.g., in maintaining ecosystem stability, are poorly understood. The role of some species is more conspicuous than others. Because we are uncertain as to how the ecosystem works as a whole, safeguarding biodiversity is one strategy to help sustain ecosystem function. Impacts on biodiversity from extraction and colonization by alien species must be understood. Research on this theme will include exploration and inventory, life history investigations, and comparison of protected and unprotected native species. Parallel research will document possible ecological changes associated with colonization by invasive species and identify possible measures to prevent or mitigate their spread.

Overview

The ecosystems of oceanic islands have a relatively high incidence of endemic species, mostly because of their geographic isolation. The Hawaiian Archipelago (2400 km in length) is situated over 3600 km from the nearest continental land mass, which accounts for endemic species comprising approximately 25% of the marine species in Hawaiian waters **(**Kay and Palumbi 1987). Another factor is the steep nature of the Hawaiian submarine ridge which can create a broad range of habitats and different ecological subsystems over a short distance. For example, shallow coral reef habitats can be less than a kilometer from subphotic ecosystems, thereby placing two very different faunal assemblages closer together and perhaps making them increasingly interdependent. Surveys of higher level taxa have been conducted throughout the archipelago but little is known about the members of the lower level taxa or their role in the ecosystem's stability. Only recently has a single research cruise focused on the inventory of the lower level taxa of one atoll in the NWHI (2006 CoML). The focus of biodiversity research in HAMER will be to address the notion that maintenance of biodiversity is a means to ecosystem stability and determine how resource extraction, habitat loss or competition with invasive species impacts overall ecosystem function. Broader questions might address whether biodiversity plays a role in energy transfer between adjacent ecological subsystems such as shallow and deep habitats and its significance to the ecosystem.

Research Priorities

Surveys of native biodiversity--Systematic exploration of shallow and deep reefs is needed throughout the archipelago to identify species and make preliminary assessments of their ecological role. Part of the assessment process will be to locate sites of high biodiversity for conservation and highlight rare species that may be more vulnerable and might require protection. Biodiversity should also be considered in the context of protected species and the role they may play in the recovery of threatened and endangered taxa.

Impact of invasive species on biodiversity and ecosystem status—More than 340 marine introduced species have been identified as alien or cryptogenic in the Hawaiian Archipelago (Eldredge and Smith, 2001). Not all alien species become invasive. Little is known about their biology and ecology and possible synergies among alien species and natives. There is a complete lack of understanding about how environmental conditions might cause an alien species to become an invasive threat or how these possible impacts change over time. Basic research is needed to carry out prevention, early detection, assessment, eradication, and control of alien species. Better-developed tools are needed to effectively manage maritime vectors and pathways in the transfer of alien species into the Hawaiian Archipelago and within the archipelago. Inherent to this will be a better understanding of taxonomy and species distributions, basic requirements for recently identified invaders, invasiveness of alien species, ecosystem community robustness, ecological shifts, and climate change. Although much of the research has and will focus on individual species, a more concerted effort needs to address habitat and mechanisms that cause invaders to have ecosystem-wide effects. Finally, social and economic impacts need to be addressed in determining the appropriate management regime. Overall, a better understanding of ecosystem, social, and economic impacts through research can help determine appropriate management strategies for pivotal species: endemic, vanishing, alien, and invasive species.

Impacts of removals on biodiversity—In addition to inventory, some biodiversity research will be focused on the community implications of removals or loss of individual organisms or biotic components associated with fishing, habitat degradation or invasive species eradication efforts. The ecosystem response to such removals could vary depending on whether they leave a void in the trophic web or there are similar taxa that temporarily occupy the niche while the impacted native taxa recover. Alternatively, competitive displacement could occur in which other taxa dominate the voided niche, reducing the likelihood of impacted native taxa ever recovering. Although impacts to the food web are used as an example above, it is possible removals could result in other changes in biotic assemblages, such as competition for space, klepto-parasitism, home-range modification etc., all topics which would be reasonable to study under this theme.

Table 4.--Program and mission elements for the native biodiversity and invasive species theme.

Native Biodiversity and Invasive Species Objectives	Focus Areas	Example Investigations	Mission Element	Final Product
Surveys of biodiversity (native and alien)	• Taxonomy • Life History	• Species ID and Inventory • Habitat requirements • Ontogenic stages	B-SI[1] B-LH[2]	• Knowledge of species are present • Their environmental tolerance • The range of habitats and dispersal capabilities
Impacts of invasive species on biodiversity	• Prevention • Eradication • Natural habitat resilience • Degraded habitat resilience	• Monitoring/detection of vectors & pathways • Taxa control and restoration strategies • Profiling hubs for invaders and endangered taxa • Susceptibility to colonization • Spatial risk assessments • Rates of spread and loss	BI-SM[3] BI-H[4]	• Monitoring of known pathways and hubs (e.g., Midway Island) of dispersal of invaders & loss of endangered taxa • Early detection and response to invaders. • Adoption of strategies to eradicate arriving invaders and protect endemic and endangered taxa • Identification of which habitats are at risk • Potential magnitude of the impact
Impacts of removals and loss on biodiversity	• Impact of fishing removals • Impact of habitat loss associated with development • Response to eradication efforts	• Displacement • Trophic changes • Habitat alteration • Behavioral changes	BR-R[5]	• Understand the ecological implications of loss of endemics, establishment of invaders or both. • Distinguish the ecological effect of invaders from natural variability

Notes:

*See Appendix G for mission descriptions
****Mission elements:**
B = Biodiversity
[1]Survey Inventory
[2]Life History
[3]Invasive: Surveillance/mitigation
[4]Invasive: Habitat research
[5]Removals: Recovery from removal

Connectivity

Research theme: The appropriate scale at which to monitor and manage ecosystems needs to be clearly understood. This requires an understanding of spatial and temporal exchange within physical and biological processes to identify ecological boundaries between subregions and assess the rate and pattern of biodiversity evolution in the archipelago. The research on this theme will focus on physical oceanography and the biological processes that may link one part of the Hawaiian Archipelago to another.

Overview

One of the major goals of this strategic plan is to achieve an understanding of the mechanisms regulating the abundance and distribution of marine populations throughout the Hawaiian Archipelago. By understanding these processes, it should be possible to generate theory capable of predicting the effects of changes in physical and biological parameters on the dynamics of these populations. A critical component of this goal is determining the rates of exchange, or connectivity, among subpopulations of marine species and communities. This connectivity has a direct bearing on ecosystem diversity, endemism, replenishment, and resilience. At this point, there is only a rudimentary understanding of the rates, scales, and spatial structure of this exchange. This lack of knowledge is a major impediment to the management of marine resources for sustainable fishing, maintenance of biodiversity, recovery of endangered species, and other goals in the face of climate change, natural disasters, habitat degradation, and other ecosystem threats.

For most coral reef organisms, this exchange takes place at the larval stage, and the extent of larval dispersal has traditionally been inferred from the duration of the pelagic larval dispersal stage, from the modeled movements of passive particles by low-frequency currents, or from analyses of population variation in mitochondrial or nuclear genomes. Recently, these estimations have been shown to be inaccurate. For many marine larvae, the effective dispersal distance is far shorter than their projected potential (Jones et al., 1999; Swearer et al., 1999; Rocha et al., 2005; Taylor & Hellberg, 2003; 2005). Larval fish recruit to local reefs at high frequency (15–89% retention: reviewed by Swearer et al., 2002) and they have much better navigation than previously suspected (Leis & Carson-Ewart, 1997; Leis & McCormick, 2002). Genetic analyses of species distribution have shown strong differentiation in the absence of obvious geographic barriers, suggesting more restricted movement of larvae and the possibility that local adaptation may be an important driver in the ecosystem. These findings have profound implications for marine resource management in the Hawaiian Archipelago and may help explain the high degree of species endemism not seen in any other tropical marine ecosystem of comparable size.

Research Priorities

Connectivity refers to coupled biophysical processes and our understanding of these processes is limited. The basic question of what larval exchange occurs between the NWHI and the MHI needs to be addressed. Thus, the following research priorities have been identified as those that will provide critical information needed to develop a sustainable resource management plan for the Hawaiian Archipelago and assist in assessing the mechanisms that explain the largely unique biodiversity of the archipelago.

Hydrodynamics of the archipelago--It is important to assess the hydrographic nature of the archipelago to understand connectivity. Patterns in the horizontal movement of water masses and sites of vertical upwelling need to be identified and monitored over time to begin developing a unified hydrographic model. A key aspect of this work will be to understand how the currents modify regional oceanic productivity. Some areas may be more structured by horizontal current flow and others by upwelling hotspots that may occur throughout the archipelago and that could funnel nutrients upward and enhance surface productivity. The physical oceanographic models developed from this investigation should also be tested with passive and smart (larval mimics) drifters.

Studies of movements of adults of various taxa--Tagging and recapture studies of adult animals using conventional and new technologies should be an integral part of any analysis of connectivity for the Hawaiian Archipelago. The tagging studies will profile the movements of important predator/fisheries species in relation to their environment (e.g., bottom topography, thermoclines, etc). Also, movement studies can identify shifts in behavior of key taxa in relation to anthropogenic changes in the marine environment. These investigations will provide more accurate population size estimates and will help ground truth current models. Much of this work will use the proven technique of passive acoustic tracking where transmitters are placed on target species and detected by acoustic receivers or "listening stations." Other tagging methodologies include transmitters that communicate the location and activities of animals via satellite or cell phone technology. In addition, development of passive acoustic monitoring devices for the Hawaiian Archipelago is a key research priority. These devices will enable researchers to monitor the sounds and possibly the movement of cetacean populations throughout the archipelago. These devices assess ambient noise, organismal sounds, and the anthropogenic sound field in the archipelago making it possible to characterize the spatial and temporal structure of the acoustic realm.

Population genetic structure--Preliminary studies on the biological connectivity of fish and invertebrates in the NWHI indicate that dispersal is highly species-dependent. The basic question is whether there are generalized patterns of distribution across the archipelago that correlate with the life histories of different taxa. Thus, the challenge will be to identify example taxa that will serve as proxies for ecosystem genetic connectivity and to develop sampling regimes that will identify genetic management units. The geographic distribution of these distinct units should enable a description of effective population size versus a census-based population size.

Transport modeling--Transport modeling employing passive (water movement) and active (larvae behavior) scenarios will provide a framework for generation of transport hypotheses to be tested in the field. Early on, available transport and movement models will be consolidated into a structured hypothesis matrix and subjected to confidence ranking. Points of uncertainty will be prioritized for work. Findings from these tests will be used to revise the models and provide a record of progress over the duration of the HAMER study.

Table 5.--Program and mission elements within the connectivity theme.

Connectivity Objectives	Focus Areas	Example Investigations	Mission Elements**	Final Product
Hydrodynamics	• Horizontal currents • Vertical upwelling	• Buoy arrays • Drifters • Remote sensing • Modeling	CH-FI[1] CH-SS[2]	• Unified hydrographic model
Movement of taxa	• Home range • Migration	• Natural marks • Sonic tracking • Passive acoustics	CM-MT[3]	• Identify boundaries between stocks on an ecological time frame
Population structure	• Reproductive pool • Behavioral structure	• Genetic composition • Visual census	CP-G[4]	• Identify reproductive subpopulations in a genetic time frame
Transport modeling	• Larval modeling (passive) • Adult modeling (motile) • Ground truth & revision	• Gap analysis and structured model generation for field testing.	C-TM[5]	• Verified predictive modeling • Identification of sources and sinks in the ecosystem

Notes:
*See Appendix G for mission descriptions
****Mission Elements:**
C = Connectivity
[1]Hydrodynamics: Fixed instrumentation
[2]Hydrodynamics: Strategic sampling
[3]Movement: Marks/tagging
[4]Population: Genetics
[5]Transport modeling

Human Interactions

Research theme: Understanding the sources, types, and magnitude of human interactions with the physical and biological components of Hawaii's marine ecosystem is essential to improving marine resource management. Currently, many of our interactions with Hawaii's marine ecosystem are undocumented and their impacts are poorly understood. This information gap seriously undermines efforts to discern between natural and anthropogenic effects. A full understanding of the impacts of human activities (both land-based and at-sea) on Hawaii's marine ecosystem is also essential for realistic ecosystem science and modeling. Research on this theme will focus on the motivations and behaviors of people as individuals and communities in relationship to the marine environment as well as on the relationship between conservation and management policies and society.

Overview

Despite its relatively remote location, human interactions with Hawaii's marine ecosystem occur from sources both near and far. Indirect sources such as climate change, ocean regime shifts, marine debris, and ocean-wide pollution may affect the Hawaiian archipelagic ecosystem as much as the variety of local stressors that are well known. Within the archipelago, there are impacts from local nonpoint sources, such as coastal runoff and sewage disposal, and from direct resource removals by fisheries and land-based activities (e.g., sand dredging for beach replenishment, deep sea water extraction for bottled water, neutroceuticals, etc.). Each of these may result in significant changes to the marine environment, and understanding their sources, magnitudes, and effects is vital to effective ecosystem science, modeling, and management. Understanding human motivations for direct and indirect use of the marine environment, and how to communicate scientific and conservation conclusions to the public are critical elements of any long-term management plan. Social science in HAMER can and will be nested in any of the six research themes as needed but this theme is dedicated to advancing the social component of ecosystem science.

There are two relatively distinct but interrelated components to research concerning the human component of marine ecosystem science. First, there is research and monitoring directed toward understanding human interactions with the marine ecosystem. Second, there is research directed toward understanding and facilitating the decision-making process itself, including stakeholder involvement.

The Council and PIFSC have initiated a detailed research planning process related to the first component through a series of workshops on ecosystem management. Central to this approach is the understanding that the ecosystem dimension to social science research involves a much broader scale of monitoring and research in terms of affected communities, moving beyond the usual idea of fishery dependent communities and directly affected fishery sectors to the community as a whole. It also involves more of an emphasis on cross-jurisdictional issues.

The second component of research concerning the human component of marine ecosystem science represents some new departures for social science research in Hawaii directed toward the marine environment. One example would be research on policy implementation, i.e., how to implement necessary new rules in a way that folks are likely to accept and comply with them. Another would be research into methods for improving the communication of complex scientific issues to the public. A third could be research into understanding and constructively balancing competing stakeholder values and interests. The Council's third ecosystem workshop, focusing on policy, will also provide some important input into this component.

Research Priorities

Monitoring human interactions with Hawaii's marine ecosystem--Human activities have affected Hawaii's marine environment since the earliest inhabitants began to populate the island chain and use its ocean resources. In the absence of comprehensive monitoring systems, our understanding of these impacts is limited. This in turn limits our ability to separate human impacts from broader ecological changes and our ability to construct robust ecosystem models. The monitoring systems required to meet this objective need to encompass all existing data collection programs (e.g., fisheries data, stream flow, water quality) as well as identifying and implementing critical new measurements and enhancing existing ones.

Understanding the impacts of anthropogenic changes to Hawaii's marine ecosystem--As local and global populations increase, environmental interactions are also increasing in intensity and scope. The range and types of impacts intertwine in complex relationships that are difficult to comprehend. Retrospective analyses of existing information can increase our understanding of ecosystem responses to human impacts, while the treatment of recent or anticipated changes to human behaviors can serve as experiments that partially isolate the effect of nonhuman from human effects. For example, the anticipated closure of some areas to bottomfish fishing will provide an opportunity to examine the effects of a variety of marine protected areas on the biomass and availability of these species (spillover) for harvest. But it is also expected to have a significant impact on the fishermen involved so it would be appropriate to study the impacts of these closures on this community and the impact of reductions in domestic catch on prices, markets and consumer behavior. Similarly, the implementation of the Papahānaumokuākea Marine National Monument provides an opportunity to analyze effects on social welfare (as well as benefits to threatened and endangered species) that have been predicted to result from prohibiting fishing in this area.

Anticipating human impacts to Hawaii's marine ecosystem--The maintenance of marine ecosystems that sustainably meet society's needs requires timely and even proactive controls on human activities. Understanding the sources and timing of changes in these activities will allow scientists and managers to anticipate and prepare for them. For example, increases in fuel prices can be expected to result in shifts out of fuel-intensive fishing methods to more fuel-efficient methods (e.g., from trolling to handlining) with concurrent impacts on target species. Similarly, new coastal developments can be expected to result in impacts to coastal waters, and ecological regime shifts are known to lead to reductions in the availability of marine resources. Each of these changes is predictable to some degree, and timely information can allow resource managers to implement necessary regulatory controls to prevent unacceptable ecosystem effects before they occur.

Table 6.--Program and mission elements for the patterns of human interactions theme.

Patterns of Resource Utilization	Focus Areas	Example Investigations	Mission Element**	Final Product
Monitoring human Interactions	• Documenting fisheries extraction • Impact of runoff and sewage discharge • Aquaculture, eco-tours, biotechnology	• Monitoring of recreational take • Retrospective analysis • Calculate errors in commercial catch reports • Development of noncatch indices • Define social aspects of place and borders for the ecosystem	H-SSSE[1] H-Hist[2]	• Knowledge of resource removals • Ratio of commercial to recreational use. • Make the local data comparable to national data • Socially acceptable means for information collection • Noncatch indices • Knowledge of other human interactions with and impacts to the marine ecosystem
Understanding anthropogenic impacts	• Effects of fishing • Habitat changes associated with development • Increased access	• Take versus catch and release • Refined spatial information on catch • Shift in target species sought over time.	H-CR[3] H-ES[4]	• Effect on resource and demand of different management measures
Anticipating anthropogenic impacts	• Change in use patterns	• Resource restoration plans • Social dimensions in setting reference points for ecosystem removals • Understanding the impact of local level exceptions	H-IR[5]	• Understanding what motivates public opinion. • Understanding resource alternatives (aquaculture) in creating demand • Anticipating adverse human impacts before they occur

Notes:

*See Appendix G for mission descriptions
**Mission Elements:
H = Human interaction
[1]Seafood safety/stock enhancement
[2]Retrospective analysis
[3]Catch & release
[4]Ecosystem shift
[5]Implementing restoration

Resilience and Recovery

Research theme: Understanding resilience and recovery processes requires a heightened level of sophistication in ecological understanding. Insight is needed on the various pathways and modifiers to ecosystem resilience. Inherent in this will be an ability to follow "trade-offs" in multiple impacts and in multiple time scales and perhaps develop a common currency (energy units?) for future analyses. This theme will tie together basic biophysical studies with broader ecosystem modeling.

Overview

Some of the most insightful studies conducted on an archipelagic scale will be those that address the capability and mechanisms that facilitate resilience in the ecosystem. These projects are divided into two categories. First are studies focused on identifying pathways of resilience that taxa or ecosystem communities may rely on when confronted with environmental stress. The second type of research addresses modifiers to resilience of ecosystem and its components. There are many popular notions about why some taxa or ecosystems appear to rebound from stress and others do not. These core concepts could be put to the test on an archipelagic scale across a gradient of environmental stress.

Research Priorities

Pathways of resilience--Four potential pathways of resilience should be examined. First, would be the ability to physically acclimate to stress. This capability is likely to vary considerably among taxa and it is important to not only consider survival but an ability to effectively reproduce. Second, there may be some level of adaptation that results from selection pressure associated with changing environmental stress levels. Genetic techniques applied to populations across the stress gradient of the archipelago may detect accumulated pools of individuals with a genetic makeup that keeps them from being filtered out by the environmental stress and thus become an avenue of resilience. Third, environmental conditions including temperature, flow, geomorphology, and other variables have been identified as having a mitigating influence that allows taxa to survive in otherwise substandard conditions. The fourth pathway is the role of community composition and morphology, e.g., changes in resilience associated with loss or excess of one or more segments of the community assemblage that result in competitive top-down pressure or an increase in bottom-up production. Similar changes could also result from changing age or size structure that lead to competitive exclusion.

Modifiers to resilience—*What is the importance of natural variability to the resilience of an ecosystem?* Does the degree of variability in an ecosystem determine its capacity for resilience? Investigation of these questions could include modeling of the Allee effect, assessing fishery depensation, or projecting ecological thresholds for phase shift.

Is ecosystem health a factor in the ecosystem's recovery from periodic disturbance? The rebound of an ecosystem may depend on maintaining established pathways of energy flow that provide the system a stable means of recovery rather than risk a transition to a different state of equilibrium. This type of work would include variants of the Intermediate Disturbance hypothesis.

How does fishing impact the resilience of the ecosystem? Disturbance associated with fishing is an important issue. Fishing can no longer be evaluated on a single-species basis and the degree to which loss of segments of the ecosystem undermine or realign established pathways of energy flow needs to be evaluated.

What are the drivers and black boxes of the ecosystem? What are the key pathways for energy flow through the ecosystem? Does a higher the rate of energy flow through the system mean more stability in the ecosystem? Oceanography, nutrient and recruitment dynamics all influence the resilience of an ecosystem.

Table 7.--Program and priorities for the resilience and recovery theme.

Resilience and Recovery	Focus Areas	Example Investigations	Mission Elements**	Final Product
Pathways to resilience	• Acclimation to stress • Role of community	• Resistance to sedimentation • Stressors role in genetic selection • Does continuous recovery (versus intermittent recovery) mean more resilience? • Competitive exclusion	R-PE[1]	• Understanding the role of anthropogenic habitats as potential brood stock for resilience • Knowing when a system has recovered • Knowing when a system won't recover
Modifiers to resilience	• Natural variability • Periodic disturbance • Fishing impacts • Pathways of energy flow • Age structure and size structure effects	• Modeling of the Allee effect, fishery depensation, • To what degree do removals impact ecosystem resilience? • Are self seeding systems capable of resilience? • What sustains high levels of predator abundance if turnover is low?	R-NV/DIST[2] R-FI[3] R-EF[4]	• Understanding the ecological impacts of natural variability • Understanding shifts in resilience associated with coastal development • Identify essential fishery management considerations

Notes:

*See Appendix G for mission descriptions

****Mission Elements:**

R = Resilience

[1]Influences of environment

[2]Natural variability/Disturbance

[3]Fishing effects on resilience

[4]Resilience and energy flow

Modeling and Forecasting

Research Theme: Estimates of carrying capacity are a critical requirement for management and for long-term planning. The process by which such estimates are derived, the scale employed, and how much the process varies over time will influence the interpretation of ecological indicators. Research on this theme will attempt to estimate carrying capacity and forecast change using the indices and metrics identified in the earlier theme with the goal of advancing ecosystem science and management.

Overview

A fundamental objective of this program is to gain insight into ecological mechanisms to assist in the eventual development of ecosystem forecasting. Modeling and forecasting is also a fundamental component of each of the other themes and the intention is to direct the findings from the wider program to support advancement of ecosystem forecast science. The goal of the theme is to develop an understanding or technology that would allow us to anticipate or predict significant changes in the ecosystem and quickly take action to minimize undesirable impacts. It is the same concept as physical forecasting of weather and climate derived from meteorological research. Weather forecasts, for example, are daily products expected worldwide and depended upon by the public and private sector as a means to minimize loss.

The objective of marine ecological forecasts would be similar─to prevent overuse, warn of impending episodic events, facilitate recovery of ecosystem goods and services, and ensure ecological resilience. Success in physical forecasting has been achieved by identifying an effect and then tracing events back in time far enough to provide a temporal interval that is useful for planning. Doing the same for the complex biochemical realm is a formidable undertaking, but the obvious direction to advance ecological science in a way that will be extremely useful for managers. Much of marine research is already focused on linking physical measurements to biological and chemical responses in the ecosystem. Examples such as linking coral bleaching to elevated ocean temperatures or predicting movement of pelagic animals based on shifting oceanographic features are solid beginnings of forecasting science.

Modeling and subsequent advances in forecasts are dependent on having suitable data with which to parameterize models. Research in the modeling theme will build on the range of findings from the other five research themes and serve as a point of ecosystem synthesis. At the minimum, these models should serve as an ecological ledger and as a hypothesis generator. The most successful and applied modeling programs identify their modeling objectives early on and prioritize what is to be measured and at what resolution and scale to ensure the data meet the modeling objectives. "Front loading" the planning for modeling in this research program is imperative to achieve the maximum benefit from this 10-year research program.

Research Priorities

Variables, resolution and relevant scale for ecological models—Aligning with objectives described in the other five research themes, considerable thought will be given to modeling early on in the program. It will be important to resolve issues about the appropriate scales and the spatial and temporal resolutions at which physical and biological processes can be identified and monitored over time. Much of this will depend on what forecasting goals are to be pursued and which parts need to be measured for success. In their most complete form, the models will be spatially explicit, in GIS or similar formats. However, this is a long-term objective and many areas may never receive the sampling needed to develop models to this level of sophistication. Furthermore, the ability of the program to be able to transfer ecosystem science to other areas depends on having a strategy to develop ecosystem models with "compressibility" that are more simplistic and work at lower resolutions for transfer to data poor situations. The idea is that these models can be quickly implemented in other areas with minimal data and later expanded or increased in resolution as new data are collected.

Review existing models and conduct a gap analysis. Model formulation—ecological linkages and patterns--Available models need to be inventoried and reviewed, and gaps need to be identified. Current models being used in the archipelago are the first steps to broader ecosystem modeling. In many cases, they provide the hypotheses for the first set of projects. Examples include oceanographic circulation models, trophic models, transport models, productivity models, and carrying capacity models. There are notable gaps in each of these model types. Trophic models have been largely dependant on a top-down approach to identifying trophic links, but less understood is the energy flow from oceanic nutrients through primary productivity and the lowest trophic levels into upper reaches of the food web. Oceanic productivity modeling has demonstrated clear spatial patterns in ocean productivity but has been unable to trace the path of the energy flow into the community. Transport models have identified large-scale patterns in ocean circulation but need to establish where the sources and sinks are for larval populations. Of the modeling efforts, carrying capacity modeling will remain an important focus. Historically derived for taxa of particular interest (e.g., fish stocks and protected species) to estimate yield capacity, recovery potential, or allowable levels of use for these single-species populations, these models will be revised and expanded to look at carrying capacity in the context of ecosystem stability and resilience.

Parameter research and model validation--Generally, the modeling and forecasting effort will rely on the data and findings from studies in the other research themes. However specific research will be needed to parameterize a prioritized modeling effort. These studies would be strategic in nature with the goal of filling a conspicuous gap in the model. Examples include determining the vertical movement and motility behavior of larvae for transport models, determining the role of the mesopelagic boundary layer in the reef's food web, and calibration of age and growth parameters for a carrying capacity model. Targeted studies would also be conducted to assess the validity of the models. If a study identifies a first order response to coral bleaching or some other effect then additional work to quantify second and third order consequences may be a priority. The research conducted in this theme will fill those gaps identified in the review of available models that were not addressed by studies under other research themes and provide some appraisal of confidence in the model results so that managers can understand the utility and risk associated with model use.

***Developing a capability for ecosystem forecasting*--**Many of the models currently in development will form the basis of a forecasting effort. Many of these are static models that are largely conceptual in nature and their utility for forecasting will depend on how well they can be converted or support tracking the dynamic changes of the environment. Temporal change is inherent in forecasting and this represents the primary challenge to selecting viable indicators that effectively detect changes with documented implications for ecosystem change. Obvious examples include sea level rise, coral bleaching, and fishery responses. The hope is that eventually model sophistication will be such that "trade-offs" can be followed across multiple impacts and in multiple time scales, perhaps by working in a common currency (energy units?).

Table 8.--Program and mission elements for the modeling and forecasting theme.

Modeling and Forecasting	Focus Areas	Example Investigations	Mission Elements**	Final Product
Variables, resolution, and scale	Identify • Parts to be measured • Clear transitions from physical to biological • The scale at which predictions are desired	• Identify short paths of energy flow • Scale/resolution needed to represent process. • Establish statistical power	F-Map[1]	• Spatially explicit model • Compressibility of the model for data poor situations • Cost effective implementation and monitoring
Gap analysis for ecosystem models	• Keystone species • Top-down structuring • Bottom-up structuring	• Turtles/herbivorous fish control of algae • Apex predators structuring of the community • Fish life spans	F-CS[2]	• Balanced ecological models
Parameter and validation research	• Ecological black boxes	• Vertical behavior of larvae • Trophic validation • Fishery calibration of age and growth parameters	F-MQC[3]	• Revise and evaluate model performance
Forecasting capability • Short-term • Long-term	• Immediate response to physical variables • Trophic response • Integration of transport and oceanic productivity models	• Coral bleaching • ECOPATH/ ECOSIM • Fishery data as an inroad to ecosystem modeling	F-Predict[4]	• Predict ecosystem response to natural and anthropogenic change

Notes:

*See Appendix G for mission descriptions
****Mission Elements:**
F = Forecasting
[1]Mapping
[2]Community structure
[3]Model quality control
[4]Forecasting (scenarios)

HAMER EXPERT PANEL REVIEW

A panel of national ecosystem experts was brought to Honolulu for a 3-day workshop to undertake an independent review of the HAMER plan. Most of the first 2 days involved a series of presentations describing the research by agencies that operate in Hawaii. This included an overview of the type of science that has been conducted in the past and projects that are currently underway. The second half of the meeting was left to the panel to critique and discuss the merits of the HAMER plan and make comments as they saw fit. Attached are the panel's comments as submitted, its terms of reference, and the agenda for the workshop.

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Panel Comments

Report of the HAMER Plan Review Panel

Tim Essington, (Chair), Jerald S. Ault, and David Fluharty

We appreciated the opportunity to join in the planning efforts for collaborative research under the Hawaiian Archipelago Marine Ecosystem Research [HAMER] program. Our review is based on the program document [Draft July 31, 2007] and 2 days of detailed presentations covering the history of marine research in the Hawaiian Archipelago, the status of current research and plans for the future to 2020.

The report is organized around the major comments and recommendations of the HAMER review panel and does not represent a systematic response to each section of the HAMER document. We emphasize that our comments focus on areas where we determine the Draft HAMER plan can and should be strengthened. Our tacit acceptance of the bulk of the report is an indication that we are generally positive in our support of the directions proposed.

Comments and Recommendations:

HAMER has the potential to become a nationally recognized leader in ecosystem science and research partnerships, but realizing this potential requires that specific structural and thematic areas are established.

Opportunities: The HAMER plan is designed to lead ecosystem-scale research in a nationally and internationally important area. The protection afforded to the newly established Papahānaumokuākea Marine National Monument [PMNM] together with the contrast provided by the main Hawaiian Islands provides unique opportunities to assess the impacts of anthropogenic stressors on reef ecosystems. The explicit partnerships already developed among multiple federal and state agencies as well as academic institutions and nongovernmental organizations are integral and necessary components of this research. There are already promising signs of new cooperation and integration across institutions (e.g., the PMNM has adopted the HAMER research themes to help drive its science programs and general management planning process for research). The collaborative framework for ecosystem scale monitoring and research is entirely consistent with national agendas. This proposed research plan builds upon extensive prior work in the area but also represents a significant incremental advance through improved coordination, integration, and resources. Finally, the vision, goals, and objectives of the HAMER plan comprise an important preemptive strategy to maintain, protect, and preserve aquatic resources and are thereby consistent with national agendas—especially the efforts to develop ecosystem approaches to management as expressed in the National Ocean Strategy of the Committee on Ocean Policy and the Pew Oceans Commission. Fortuitously, unlike comparable geographic areas where similar research plans might be implemented, the Hawaiian Islands Archipelago falls under a single country jurisdiction.

Requirements: The explicit cooperation of multiple agencies representing the State of Hawaii, U.S. Departments of Commerce and Interior, academic and private institutions is essential for the HAMER plan to succeed. The program should continue to emphasize the dual research aims of (1) providing improved scientific understanding of ecosystem structure and dynamics for policy decisions regarding use of the Hawaiian Islands Archipelago; and (2) providing knowledge that can be broadly applied to other U.S. ecosystems. A dedicated component of data synthesis and analysis (see below) needs to be added to the Draft HAMER plan to ensure cost-effective and targeted integration of research across themes, to enhance the efficiency of program and to produce synergies through consolidated efforts across research themes.

Develop a plan for data synthesis to achieve HAMER Plan vision.

Development of ecosystem-based research to derive more holistic understanding requires not only the incorporation of diverse ecosystem elements, but also a concerted and devoted plan for synthesis. We view synthetic research—conceptual and quantitative work directed at integrating disparate data to answer large-scale questions—to be a key feature necessary to make HAMER a substantial advance over existing monitoring and research in the Hawaiian Islands Archipelago. Moreover, this feature is essential for making HAMER a pioneering and leading research program globally. We believe it is possible to use existing data as guideposts for scientific pursuits and resource leverage. We also note that this effort will require use of dedicated funds to reorganize and reprioritize research components.

Specific recommendations concerning the synthesis arm of the research program:

(1) Synthetic research is needed at the onset of the research program to collate and organize existing data from ongoing monitoring efforts, use those to identify information/understanding gaps, perform statistical power analyses to enhance further data collection and to establish priorities based on noted gaps in existing data.

(2) Synthetic analysis needs to be conducted continuously and in an integrative and adaptive fashion with ongoing data collection to ensure that data priorities are updated and modified as needed.

(3) This synthesis will require the development of information systems to organize existing databases and new data collected as part of the HAMER plan.

A central element differentiating this work from ongoing work is the potential for holistic, large-scale assessment of a large marine ecosystem. Synthetic analysis, development of information systems and administration thereof will require dedicated efforts and fiscal resources that are not presently considered in the draft HAMER document. To this end, we encourage the development of a focused "Research Center" as a means to provide a cohesive direction, to oversee synthesis, and to centralize administrative responsibilities. The leaders of this Center could be visible and articulate spokespersons for the research program and serve as "go-to" personnel for individuals within and outside of the HAMER effort. Properly organized and executed, HAMER may represent the paradigm for these kinds of ecosystem management initiatives.

A transparent and mutually-agreed-upon process for prioritizing research projects and funding allocations is needed.

The HAMER Plan draft document outlines an ambitious plan to explore small- and large-scale processes in the natural, physical and societal ecosystems of the Hawaiian Islands Archipelago. The panel recognizes a need for cost-effective forward-looking strategies to achieve the vision statement of HAMER, specifically via a transparent process for allocating funds among disparate research themes and to topics within them. This process should have at least the following components:

(1) An advisory board containing members of participating agencies and scientific specialties

(2) An agreed-upon vision for the state of ecosystem science and resource protection for the year 2020, from which decisions makers can "work backward" to identify key steps/data gaps and to develop realistic timelines needed to achieve this vision

(3) Data synthesis to inform analyses and design for implementing the HAMER plan, one that integrates components at appropriate time-space scales and meets theme objectives

(4) Recognition by all parties that this process may involve iterative changes to existing monitoring designs, data collection or modeling programs to achieve economies of scale or to capture more important elements not presently considered

The panel also suggests a two-tiered approach to evaluating research priorities. Priority one projects are those that provide key foundation products, e.g., improved sampling designs and habitat mapping. Priority two projects are those that elucidate elements of ecosystem structure, processes or drivers. The burden should be on research groups to present a reasonable justification that the structure/process examined is a key component of the HAMER operational model (see below), especially research activities that target key uncertainties. Frequent updating and modification of conceptual and quantitative models should prove essential in identifying these key uncertainties.

An operating model should be developed and used to guide prioritization decisions and to enhance integration and synthesis of research.

The draft HAMER plan contains a broad vision statement and specific research themes. These research themes span multiple scales of social, biological, chemical, and physical processes. *The review panel agreed that the research themes specified in the HAMER draft plan were appropriate and highly relevant to improve ecosystem science and* *resource management.* The panel also recognizes that broad topic area and conceptual overlaps exist among the research themes. The panel therefore suggests that the plan will be improved by developing an operating model that can serve as a gateway between vision statement and the specific research themes. This operational model should highlight commonalities between research themes, areas of synergies and contributions of research themes to the overall project vision. We provide one example of a potential operating model, drawing on similar guidelines used in other Integrated Ecosystem Assessment programs. This example is only intended to be illustrative, not prescriptive.

Example operational model:

Goal: Enhance scientific understanding to improve predictive and forecasting capabilities for the Hawaiian Island Archipelago Marine Ecosystem.

Operational Model: HAMER will explore the *ecosystem structure and dynamics* of the insular marine waters of the Hawaiian Island Archipelago and identify ecosystem *drivers and stressors* and their impacts therein.

System structure and dynamics at multiple time/space scales:

Populations	Communities	Food Webs	Ecosystem
Connectivity Size / age structures Recovery / resilience	Species interactions and composition, Biodiversity	Integrated networks, flows of energy and matter. Trophic levels. Ecological indicators	Geomorphology and benthic habitats, environmental forcing

Drivers and Stressors and impacts therein:
Fishing, diseases, invasive species, other recreation, eutrophication, sedimentation, climate change

An accounting of present financial expenditures on the HAMER ecosystem research themes and the increments needed to achieve HAMER plan goals will improve the context for developing requests for increases in funding.

Considerable research is already being conducted on ecosystem elements throughout the Hawaiian Islands Archipelago. The HAMER plan calls for substantially expanding this research and for new initiatives. However, the incremental cost needed to achieve the scientific benefits of the new vision is not clear. The case will be strengthened by elucidating this incremental financial support.

Strengthen and justify social science themes.

We fully support the emphasis placed on developing monitoring and assessment research to improve understanding of human behaviors in the context of ecosystem conservation and resource management. We believe that human interactions are an integral part of the HAMER Plan and agree with the overall statement of the theme. It is apparent that much of the social science work – primarily from the disciplines of anthropology, economics and sociology – performed so far relates to human interactions in marine ecosystems or to specific management mandates. Much of this work is qualitative and thereby insufficient for development of social models, let alone integrated models of natural and social ecosystems. As is noted by the authors of the HAMER Plan, this deficiency constrains our ability to understand and predict human behavior and to determine the temporal and spatial scales at which human activity occurs. While the remote NWHI portion of the Hawaiian Archipelago supports limited human access and provides opportunities for specific studies, the MHI are expected to be exposed to increased human uses both in the coastal and oceanic areas but also through terrestrial development.

Discussions concerning the process of research prioritization identified above must be devoted to the apportionment of funding among themes. The relative amounts needed to obtain quantitative ecosystem-level monitoring data for human activities and impacts, construction of models and research that addresses a better understanding of what motivates human interaction are considerably larger than the present allocations. Marine ecosystem and human interactions define quality of life in the Hawaiian Archipelago but learning how to set policies that sustain that quality is a compounding need under present trends. For HAMER to be successful the deficiencies of human interactions monitoring and research cannot be treated as an "add-on" but they must be perceived and treated as integral. Ongoing monitoring and research to meet legislative mandates can complement but not supplant additional research at ecosystem level scales.

Analytical and empirical research should be organized and conducted in an integrated, cooperative fashion.

We recognize that the culture of scientific enterprise often results in a tendency towards specialization and isolation within disciplines. That would appear to be a major mistake in the evolution of the HAMER Program. We emphasize the great advantages that can be had by fully integrating modeling and other quantitative analyses within the other research themes. We strongly encourage the development structural elements in HAMER that promote a tight integration between data collection and quantitative analysis/modeling. One scheme towards this integration is to adopt a systems approach to program design, starting with the model of Adaptive Ecosystem Assessment (AEA—Holling, Walters and Hilborn circa 1970s). AEA features focused workshops consisting of modeling teams, research scientists, resource managers and decision makers to develop "working models" of systems to develop fresh hypotheses, identify deficiencies in existing data and thereby direct future data collection. This interactive framework can greatly improve the contribution of both research arms to the enterprise and also fosters an open exchange of ideas, concepts, and data among scientific specialties.

Summary and Conclusions:

The framework laid out by the HAMER Plan may produce a model for structure, interactions, and collaborations in the evolving field of marine ecosystem science. A clear focus on synthesis and analysis of existing databases will be required to establish performance, set baselines, optimize survey designs and fill critical research gaps. It will also allow the identification of general principles that are transferable and potentially result in the HAMER Plan leading the way in the world's marine ecosystem research.

Expert Panel Review of the Hawaiian Archipelago Marine Ecosystem Research (HAMER) plan

University of Hawaii, East-West Center
August 14–16, 2007

The goal of the Hawaiian Archipelago marine ecosystem research plan is to understand the archipelago's marine physical and biological environments, their dynamics and their interactions with human beings as a single connected system leading toward improved resource management. In developing the HAMER plan, an *ad hoc* review panel will be convened to comment on the document and prepare a report for inclusion in the plan. The terms of reference for the review panel follow.

Terms of Reference:

The panel and appointed chair will be tasked with reviewing and commenting on the HAMER plan. The panel will meet for 3 days with portions of the first 2 days made up of presentations by HAMER collaborators on the availability of data. The third day will be dedicated to the preparation of the panel report. The panel chair will be responsible for the delivery of the report no later than 4 weeks after the meeting.

Each panelist is asked to record the details of findings, including points such as

1. Discussing the value of a multiagency approach to advance ecosystem science for management.

2. Commenting on the six HAMER themes of emphasis and the five guiding principles the plan employs to ensure management relevance.

3. Identifying notable gaps in the plan and any modifications needed to complement existing national/international ecosystem initiatives.

4. Highlighting areas where HAMER is uniquely suited to assess ecosystem principles that are relevant to the wider international framework.

5. Suggesting priorities in the range of proposed work.

Hawaiian Archipelago Marine Ecosystem Research (HAMER) Plan Expert Panel Review

Agenda

August 14–16, 2007
Honolulu, Hawaii

Location:
East-West Center
Asia Room

August 14th—Contextual Presentations (20-min talks with 5-min questions)

8:00 am Continental Breakfast

8:30 Welcoming and Orientation *Sam Pooley*

8:55 Oceanography of the Hawaiian Archipelago *Jeff Polovina*

9:20 Geography and habitat of the Hawaiian Ridge *Joyce Miller*

9:45 Archipelago's academic research history *JoAnn Leong*

10:10 Break (15 min)

10:25 Multiagency initiatives in the NWHI *Malia Chow*

10:50 Archipelago's management research history *Dan Polhemus*

11:15 Patterns of Resource Use *Jarad Makaiau*

11:40 Lunch (1 h)

Available data by HAMER themes (20-min talks with 5-min questions)

12:45 HAMER planning process *Frank Parrish*

Indices and metrics research in Hawaii
1:10 CRED monitoring *Robert Schroeder*
1:35 CRAMP monitoring *Kuulei Rogers*

2:05 Break (15 min)

Biodiversity and Invasive species
2:20 Census and inventory *Amy Hall*
2:45 Invasive species *Tony Montgomery*

Human Interaction research
3:10 Fisheries monitoring *Dave Hamm*
3:35 Economics *Minling Pan*

4:00 Panel confers

4:30 End of day

August 15th—Available data by HAMER themes (cont'd.)

8:00 am Continental Breakfast

Human Interaction research (cont'd.)
8:30 Social science *Stewart Allen*

Connectivity Research in Hawaii
8:55 Hydrographic model /Larval work *Don Kobayashi*
9:20 Fish movements *Yannis Papastamatiou*
9:45 Genetic connectivity *Matthew Craig*

10:10 Break (15 min)

10:35 Protected species connectivity *Charles Littnan*

Resilience and recovery research in Hawaii
11:00 Corals disease *Megan Ross*
11:25 Fisheries *Robert Moffitt*

11:50 Lunch (55 min)

12:50 Birds *Beth Flint*
1:15 Protected marine animals *Jason Baker*

Modeling/ forecasting in Hawaii
1:40 Modeling framework *Don Kobayashi*
2:05 Stock modeling *Jon Brodziak*
2:30 Forecasting *Jeff Polovina*

2:55 Break (15 min)

3:15 Open discussion and Q&A

4:30 End of day

August 16th—Panel discussion and report preparation

8:00 am Continental Breakfast

8:30 Convene Panel

10:00 Break

12:00 Lunch

3:00 Break

3:15 Informal oral presentation of panel findings

4:30 End of meeting

APPENDICES

Alphabetical List of Mission Acronyms.. A-1

Matrix of Mission and Research Themes B-1

The HAMER Plan and Other Marine Ecosystem Research Initiatives C-1

HAMER Management and Drafting Teams D-1

Participants List for the Focus Groups for the Six HAMER Themes E-1

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Biodiversity G-7
Connectivity G-13
Human Interactions G-19
Resilience and Recovery G-25
Modeling and Forecasting G-29

Appendix A.--Alphabetical List of Mission Acronyms

B-LH	=	Life History
B-SI	=	Survey Inventory
BI-SM	=	Invasive: surveillance/mitigation
BI-H	=	Invasive: habitat research
BR-R	=	Removals: recovery from removal
CH-FI	=	Hydrodynamics: Fixed instrumentation (remote sensing, arrays)
CH-SS	=	Hydrodynamics: Strategic sampling (ship based, drifters)
CM-MT	=	Movement: Marks/Tags
CP-G	=	Population: Genetics (regional profile across the taxonomic base)
C-TM	=	Combination of physical and biological data to address dispersal and movement.
F-Map	=	Mapping
F-CS	=	Community structure
F-MQC	=	Model Quality Control
F-Predict	=	Forecasting (Probability scenarios)
H-CR	=	Catch & release
H-ES	=	Ecosystem shift
H-Hist	=	Retrospective analysis
H-IR	=	Implementing restoration
H-SSE	=	Seafood safety and stock enhancement
I-BHC	=	Benthic habitat change
I-BSA	=	Biotic Sensitivity Analysis
I-CM	=	Chemical Monitoring
I-FAC	=	Fish assemblage composition
I-PM	=	Physical Monitoring
I-RS	=	Remote sensing
R–EF	=	Links between resilience and energy flow
R-FI	=	Fishing effects on ecosystem resilience
R-NV/DIST	=	The role of natural variability in resilience
R-PE	=	Influences of environmental changes on resilience

Appendix B.--Matrix of Mission and Research Themes

Missions Science objective	Research Themes					
	Indicators and Metrics	Biodiversity	Connectivity	Human Interactions	Resilience and Recovery	Modeling and Forecasting
B-LH	S	P				
B-SI	S	P	S			
BI-SM		P		S		
BI-H		P		S		
BR-R		P			S	
CH-FI	S		P			S
CH-SS	S		P			S
CM-MT			P		S	S
CP-G		S	P			
C-TM	S		P			S
F-CS					S	P
F-MQC	S	S	S			P
F-map	S					P
F-Predict	S				S	P
H-CR			S	P		
H-ES				P	S	S
H-Hist				P		S
H-IR				P	S	
H-SSSE				P		
I-BHC	P			S	S	S
I-BSA	P	S				S
I-CM	P			S		S
I-FAC	P			S		S
I-PM	P		S			S
I-RS	P				S	S
R-EF	S	S		S	P	S
R-FI				S	P	S
R-NV/Dist		S		S	P	S
R-PE	S				P	S

P = Primary science objective
S = Secondary science objective

Appendix C.--The HAMER Plan and Other Marine Ecosystem Research Initiatives

There are many large scale marine ecosystem research programs that operate on a regional, national or international level. They can be generally classified into two types of programs. The first specializes in organizing and maintaining observing systems that are focused on census, assessment, and monitoring. Examples include the Integrated Ocean Observing System (IOOS) of the National Oceanographic Partnership Program (NOPP) and the equatorial Tropical Atmosphere Ocean project (TAO) run by NOAA Pacific Marine Environmental Laboratory. Most of these operate with undefined life spans, although the Census of Marine Life (CoML) advertises its project duration at 10 years. The second set of programs includes those focused on synthesis. Examples are the National Ecological Observatory Network (NEON) supported through NSF, the International Council for Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES), Climate Impact on Top Predators (CLITOP) administered through GLOBEC and the Joint Subcommittee on Ocean Science and Technology (JSOST) which is sponsored by NSF and NOAA Ocean Service (NOS).

HAMER has elements of both program types but is primarily a venue for ecosystem synthesis with a Hawaiian Archipelago focus. HAMER is structured bottom up with its mandate outlined by Federal and State management entities from Hawaii and the science plan drafted by a cross section of regional scientists. HAMER will complement national and international ecosystem initiatives by addressing ecosystem questions of broad relevance and possibly could be a formal regional subcomponent of one or more of the national initiatives. Of the national programs listed above, HAMER is most similar to JSOST in that they both address ecosystem synthesis and have a projected life span of 10 years.

Program	Type	Objective	Geographic Scale	Time Frame
IOOS (NOPP)	Monitoring	Marine ecosystem	National	Indefinite
TAO (NOAA)	Monitoring	Equatorial climate	Pacific	Indefinite
CoML	Assessment		International	10 years
NEON (NSF)	Synthesis	Terrestrial watershed	National	Indefinite
ICES	Synthesis	Marine ecosystem	North Atlantic	Indefinite
PICES	Synthesis	Marine ecosystem	North Pacific	Indefinite
JSOST	Synthesis	Marine Ecosystem	National	10 years
CLIOTOP (GLOBEC)	Synthesis	Apex predators	Oceanic	10 years

Appendix D.--HAMER Management and Drafting Teams

Senior management team

Charles Alexander	Integrated Ocean Observations System, NOS, NOAA
Jo-Ann Leong	Hawaii Institute of Marine Biology, University of Hawaii
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Kitty Simonds	Western Pacific Regional Fishery Management Council
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Members of the drafting team

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Dan Polhemus	State of Hawaii, Division of Aquatic Resources

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Appendix E.--Participants List for the Focus Groups for the Six HAMER Themes

Connectivity

Brian Bowen—Hawaii Institute of Marine Biology
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Human Interactions

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Chris Kelley—Hawaii Undersea Research Laboratory, UH
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Indicators of Change

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Paul Jokiel—Hawaii Institute of Marine Biology
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Ecosystem Modeling and Forecasting

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Ecosystem Resilience and Recovery

Alan Friedlander—National Ocean Service/Oceanic Institute
Beth Flint—U.S. Fish and Wildlife Service
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Gerard DiNardo—Pacific Islands Fisheries Science Center, NOAA

Appendix F.--References by HAMER Section and Theme

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Appendix G.--Example Mission Elements for Each of the Six Themes

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Biodiversity G-7

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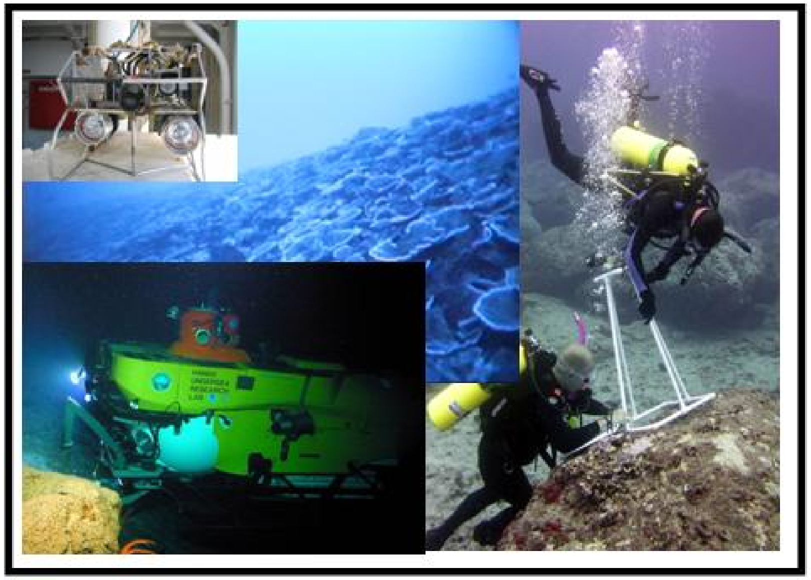
Indicators—Benthic Habitat Change (I-BHC)



Science Objectives

- Determine composition and abundance of functional groups (e.g., live coral, macroalgae, etc) at the genus/species level.
- Determine if composition and abundance of functional groups change over time.
- Track habitat changes by ecological subsystem (reef, slope, subphotic).

Mission Description

- Assess habitats in unsurveyed areas.
- Determine if benthic communities are changing over time.
- Discern most relevant indices for assessing change in the benthic community.

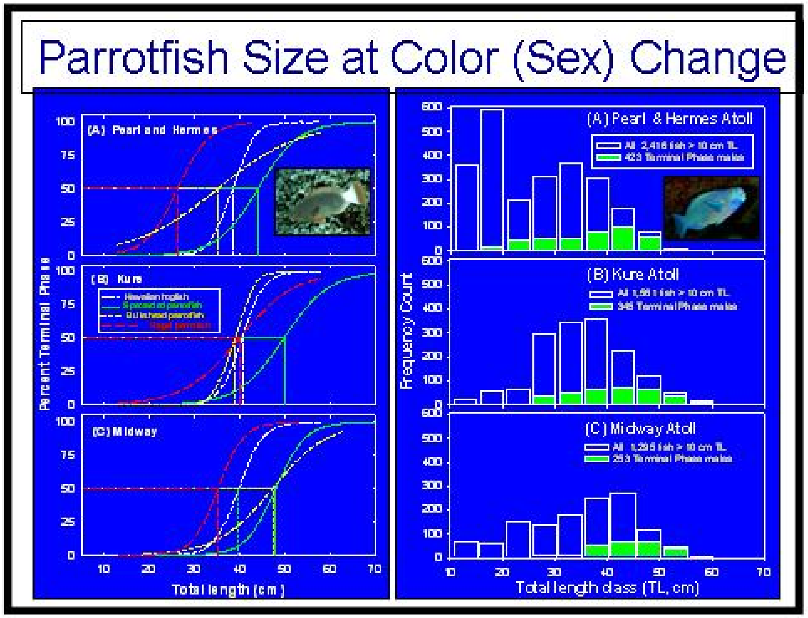
Key Infrastructure Requirements

- Ship support (60 day/yr)
- Funding for 3 staff associated with surveys, data analysis, and reporting
- Specialized support gear (e.g., digital cameras, transects, dive gear, remote vehicles, chamber support, sub time)
- Office space, computers, software, administrative oversight

Measurement Strategy

- Conduct periodic benthic surveys using standardized protocols to allow for spatial and temporal comparison.
- Develop cost-effective indices for monitoring (e.g., AUV technology).

Indicators—Biotic Sensitivity Analysis (I-BSA)



Science Objectives

- Develop metrics that provide estimates of dynamic biological processes such as body size at sexual maturity of resource species, preferably in a non-invasive and nondestructive manner.
- Evaluate the robustness of these metrics as proxies for direct estimates and provide them as input to stock assessments.

Mission Description

- Analyze and evaluate spatial and temporal patterns of change in key population metrics and report on patterns periodically to resource managers.

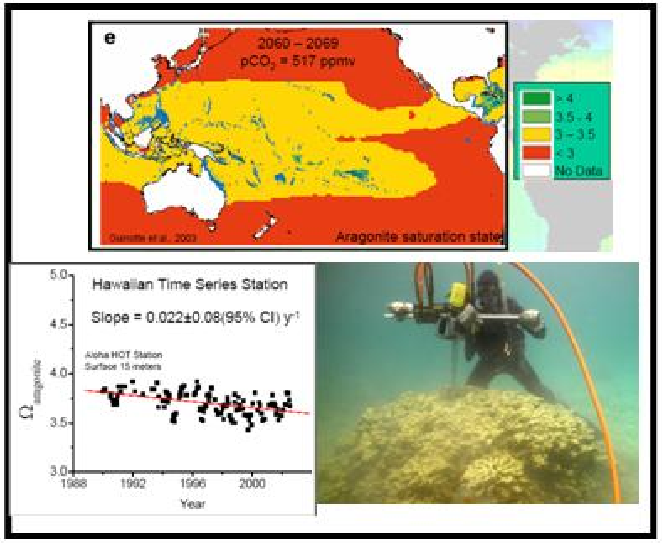
Key Infrastructure Requirements

- Dedicated sea-days on NOAA ships
- Dedicated staff funding for field and analyses
- Access to the Monument for comparative research

Measurement Strategy

- Conduct periodic, broadscale spatial in situ surveys of the fish fauna throughout the archipelago that complement the existing monitoring efforts.
- Employ a comparative approach using the Northwestern Hawaiian Islands.

Indicators—Ocean Acidification (I-CM)



Science Objectives

- Understand the temporal and biogeographic changes of the carbon system (ocean acidification) in the Hawaiian Archipelago.
- Consider current calcification rates in relation to the archipelago's historical rates.

Mission Description

- Determine changing calcification rates of corals, coralline and Halimeda algae as a result of ocean acidification.
- Determine spatial and temporal patterns of pCO2 and pH across the archipelago.
- Develop a long-term record of SST and coral growth rates.

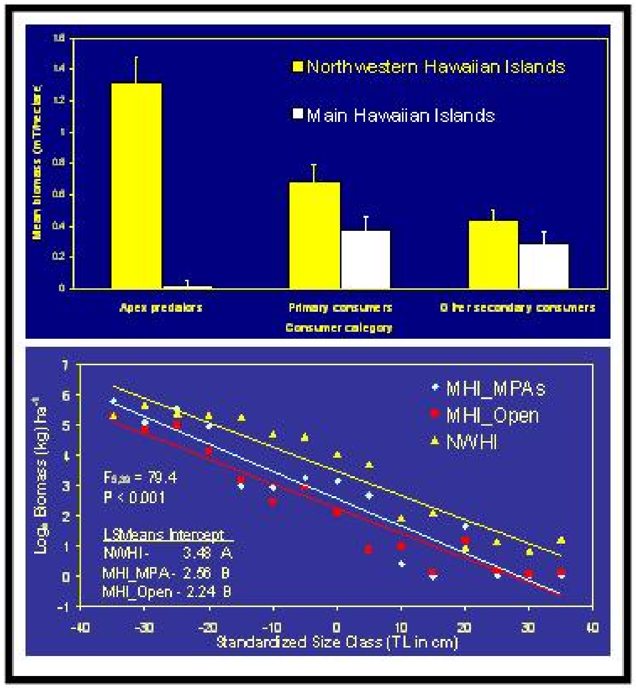
Key Infrastructure Requirements

- Funding for graduate students to conduct spatial carbon chemistry surveys during RAMP
- Funding for six carbon chemistry moorings and technician
- Funding for benthic coring equipment and personnel support for field collections, lab work
- Funding for HIMB tank experiments

Measurement Strategy

- Conduct spatial surveys of carbon chemistry (pCO2, pH, etc.).
- Use data from fixed instrumentation arrays to determine temporal variability.
- Collect benthic cores for historical record.
- Conduct tank experiments of acidification on reproduction, recruitment on benthic calcifiers.

Indicators-Fish Assemblage Composition (I-FAC)



Science Objectives

- To describe the trophic and related functional composition (eg, biomass size spectra) of fish assemblages throughout the archipelago.
- To evaluate any major observed changes in trophic structure and suggest further research to understand possible changes in ecosystem function.

Mission Description

- Characterize and monitor temporal changes in the food web and related functional structure of reef fishes.
- Communicate any major observed changes to resource managers.

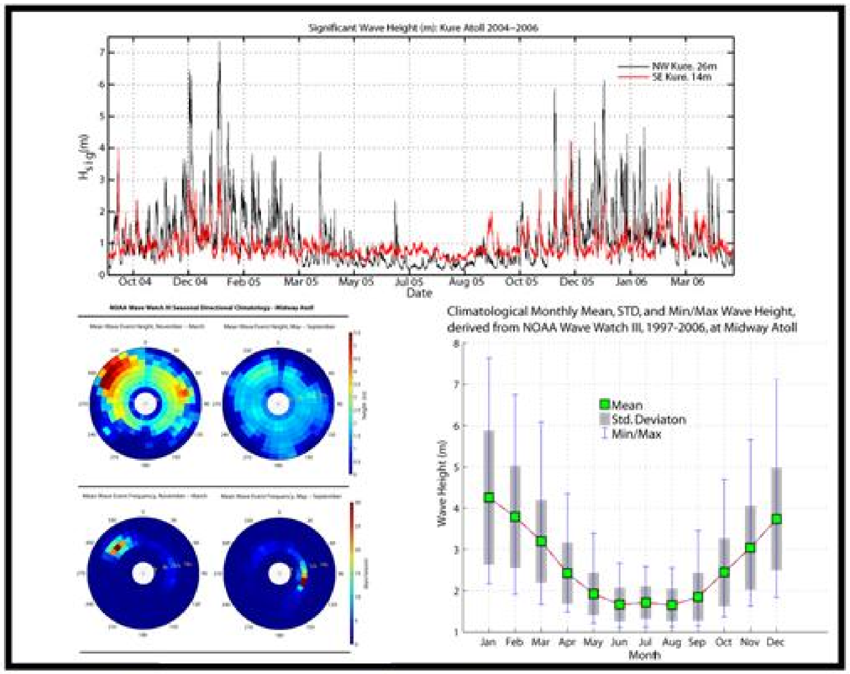
Key Infrastructure Requirements

- Exceptional days at sea availability
- Dedicated funding for survey personnel

Measurement Strategy

- Conduct periodic, broadscale spatial in situ diver-surveys of the fish fauna throughout the archipelago that complement existing surveys.
- Piggyback to all extents possible on current surveys.

Indicators—Physical monitoring (I-PM)



Science Objectives

- To identify climate change-induced changes to the physical environment.
- To understand the degree, context and implications of changes in the physical environment.

Mission Description

- Observe spatial and temporal patterns of temperature, sea level, wave dynamics, sediment transport etc., by habitat type across the archipelago.
- Develop high resolution island/atoll-by-island models of the physical environment.

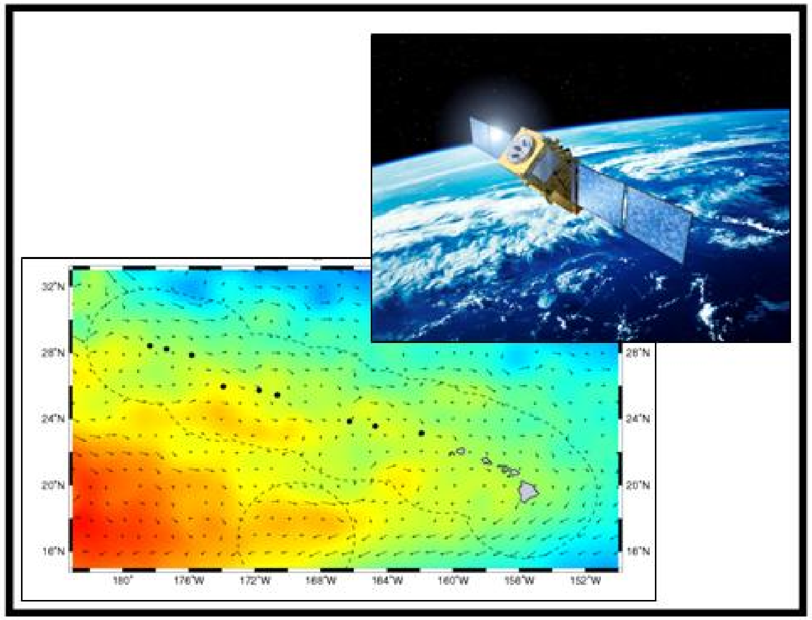
Key Infrastructure Requirements

- Data will be pulled from the fixed instrumentation array CH-FI.
- Funding for 4 full time technicians and 4 grad students for data abstraction and analysis.
- Funding for modeler, model development, computing infrastructure, IT support.

Measurement Strategy

- Determine natural variability on annual basis.
- Look for patterns of successive deviations from the annual envelope that would be consistent with climate change.
- Use successive years of data to parameterize the observe change for modeling.

Indicators—Remote Sensing (I-RS)



Science Objectives

- Establish a continuous space-based monitoring program and modeling effort suitable for short- and long-term studies.
- Construct a complete data archive suitable for monitoring of oceanographic features and indicators.

Mission Description

- Identify physical, chemical and/or biological oceanographic processes that affect local/regional habitats.
- Implement effective satellite remote sensing & modeling techniques for assessing impacts on regional habitats.

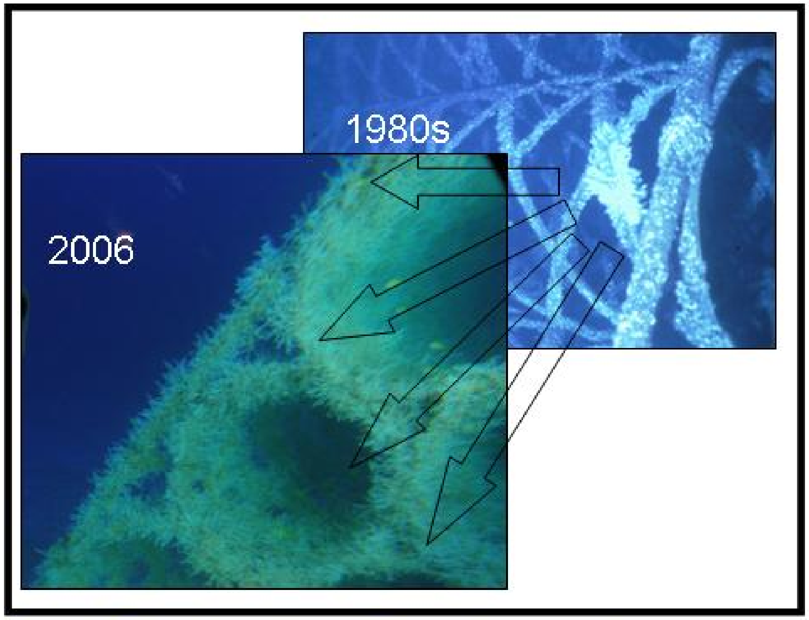
Key Infrastructure Requirements

- Computer infrastructure for modeling efforts & processing of high-volume satellite remote sensing datasets
- Funding for contract staff associated with modeling efforts

Measurement Strategy

- Create an interactive data access, monitoring, and analysis gateway via the NOAA OceanWatch—Central Pacific Office web site.
- Describe interannual and seasonal dynamics within the Hawaiian Archipelago.

Biodiversity Invasive—Habitat (BI-H)



Science Objectives

- Document the change in community assemblages due to habitat alteration from Invasive species.

Mission Description

- Identify invaders.
- Appraise their ecological consequence.

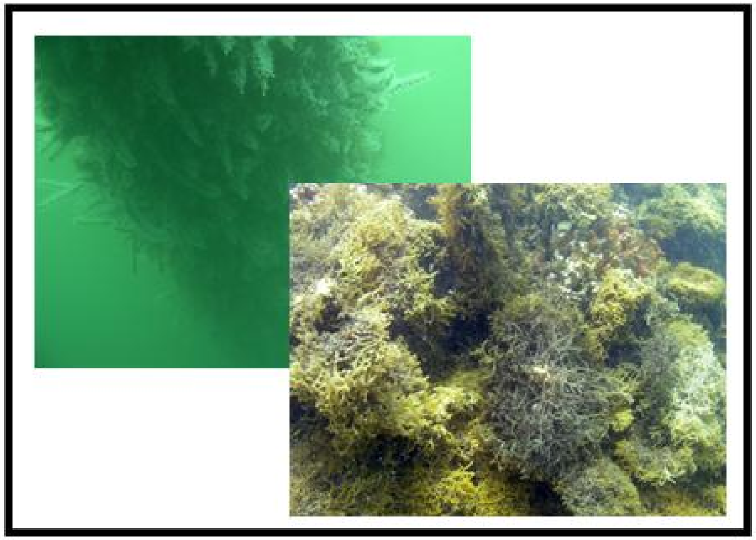
Measurement Strategy

- Review available assessments and augment surveys of shallow and deep reefs to identify state of indigenous versus invasive species.
- Monitor species diversity and changes to the ecosystem from niches being vacated or out competed.
- Look for loss of ecosystem function.

Key Infrastructure Requirements

- Gear to access ecosystems (mixed gas diving, deep ROVs, submersible time, vessels with dynamic positioning)
- Funding for contract staff associated with such surveys

Biodiversity Invasive—Surveillance Mitigation (BI-SM)



Science Objectives

- Develop a reliable approach to the detection and of alien species along known pathways and vectors.
- Develop an approach to determine the appropriate response to the detection of a new alien species.

Mission Description

- Detect new alien species introductions before they become widespread and show invasive characteristics.
- Respond by eradicating, containing, or controlling high-risk alien species.

Key Infrastructure Requirements

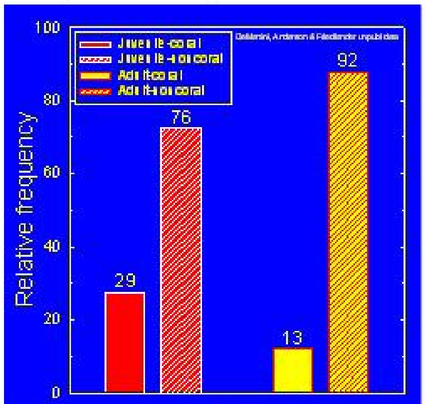
- Develop capacity (via training) with existing staff to identify organisms in the field and laboratory while supporting a local taxonomic expertise.
- Develop genetic tools to aid in the early detection of alien species.
- Acquire funding to maintain a consistent effort in monitoring and discovering the early detection of alien species.

Measurement Strategy

- Conduct comprehensive surveys archipelago wide at least annually.
- Periodically, use models to test the detection success of surveys.

Biodiversity—Life History (B-LH)

Live coral disproportionately important for juvenile fishes



Key Infrastructure Requirements

- Standard (open circuit, air) scuba equipment
- Survey gear (transect lines and reels etc.)
- Funding for staff and ship time

Science Objectives

- Characterize the relative magnitude of recruitment among habitat types throughout the archipelago.
- Describe how these relations are modified by ontogeny.
- Characterize habitat-related mechanisms that could cause interannual variations in recruitment.

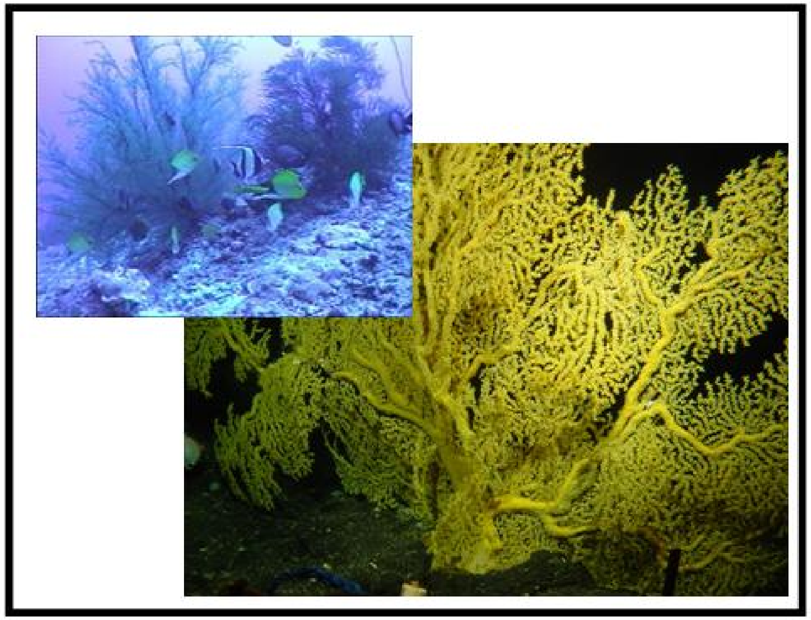
Mission Description

- Identify largely unknown relations between the recently recruited and older juveniles using the habitat.
- Assess impact of piscivorous predators on juveniles relative to habitat in the NWHI and MHI.
- Use recruit indices a year class strength for input in stock assessments.

Measurement Strategy

- Make comparative surveys in the MHI and NWHI.
- Measure "preference" of target taxa for specific benthos and functional structure (e.g., rugose live coral) using electivity indices.
- Maximize opportunities to piggyback on existing cruises.

Biodiversity Removals—Recovery (BR-R)



Science Objectives

- Document and monitor changes in ecosystems where species have been extracted (e.g., fisheries, ornamental etc.).
- Determine the ecosystem wide changes and the long-term impacts of extraction particularly for habitat components such as deepwater corals.

Mission Description

- Determine sustainability of populations subjected to extraction.
- Describe the biological characteristics, ecosystem functions, and trophic links for these taxa.

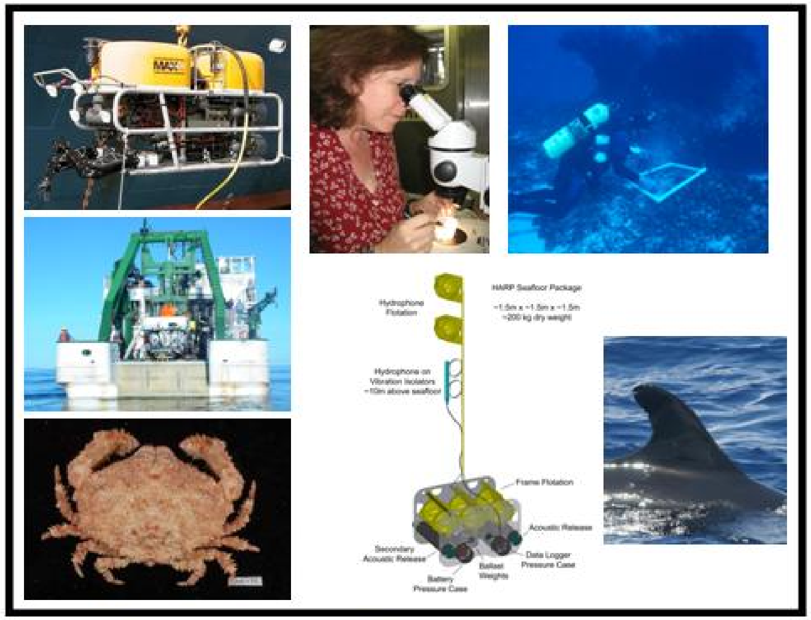
Key Infrastructure Requirements

- Improved ROV capability and wet diving infrastructure
- Platforms to allow multiple modes of access to deepwater communities concurrently
- Funding for staff to run and coordinate logistics for research expeditions

Measurement Strategy

- Conduct periodic monitoring of taxa targeted for extraction and their associated communities.
- Provide a description of key biological characters for the taxa and associated communities.

B-SI (Biodiversity Survey/Inventory)



Key Infrastructure Requirements

- Ship time with small boat support.
- Gear to access under-surveyed habitats, (mixed gas, rebreathers, submersibles, deep ROVs, support vessels with multibeam, and DP)
- Gear to collect specimens (handheld/vehicle-mounted samplers, anesthetic dispensers, specialized traps, and specimen containers)
- Acoustic, photo ID, and biopsy collection gear

Science Objectives

- Census species in reef and under-surveyed habitats (lower sublittoral, bathyal drowned reefs, seamounts, rift zones, and pelagic).
- Identify environmental zonation patterns and seasonality.
- Develop taxonomic knowledge.

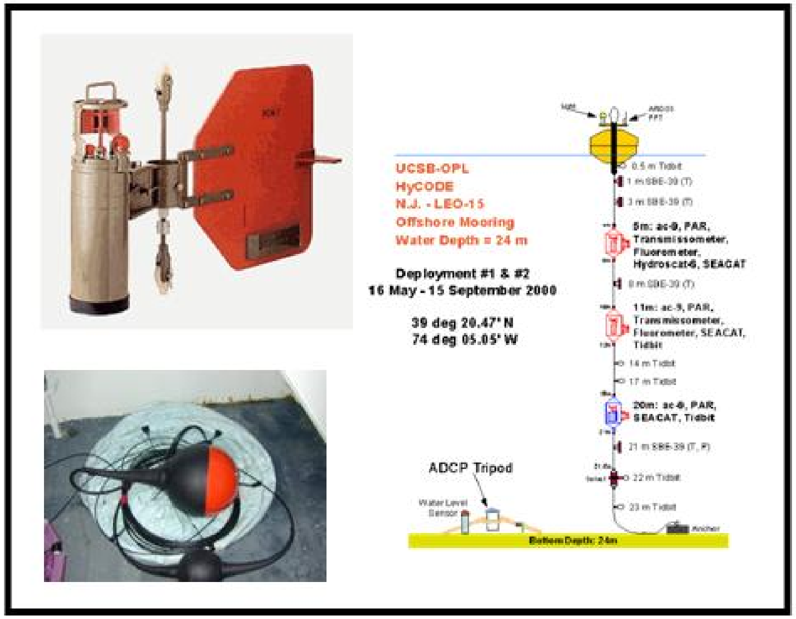
Mission Description

- Surveys focused in under-surveyed habitat types via multibeam data, and conduct baseline visual/video surveys.
- Process collected voucher specimens.
- Develop taxonomic knowledge.
- Analyze survey data in relation to environmental data.

Measurement Strategy

- Conduct a series of regional expeditions to selected study sites.
- Prioritize expeditions relative to management need and efficiency in logistics.
- Develop taxonomic collaborations to take advantage of expertise worldwide.

Connectivity Hydrodynamics Fixed Instrumentation (CH-FI)



Science Objectives

- Understand archipelago scale ocean circulation patterns over the time scales associated with larval transport.
- Document atoll and nearshore circulation patterns to estimate: residence/retention times, likelihood of self-recruitment and dispersal.

Mission Description

- Observe spatial and temporal patterns of ocean circulation on archipelago, atoll, and nearshore scales.
- Use observations to validate hydrodynamic model development.

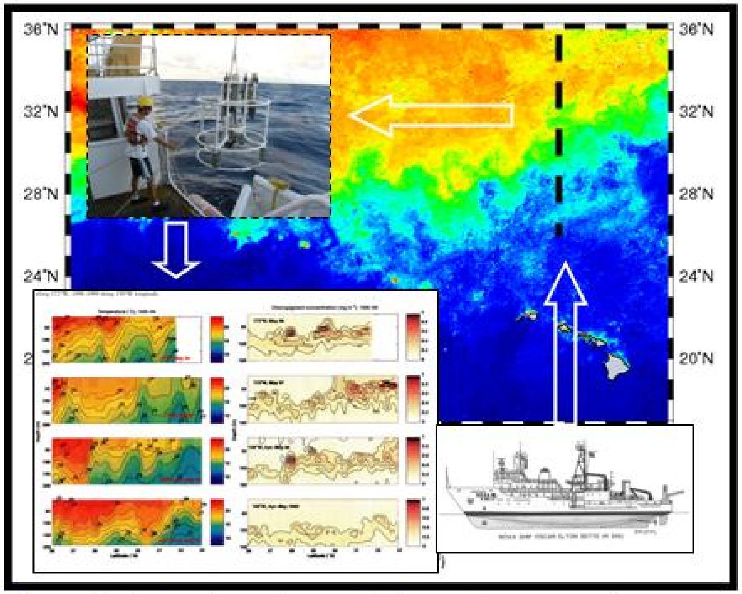
Key Infrastructure Requirements

- Funding for 100 APEX profiling floats, 2 long-range profiling AUVs, 10 ADCPs, and 10 current meters 30 SBE26+ wave and tide recorders
- Funding for 1 oceanographer, 2 technicians, and 4 grad
- Funding for IT infrastructure and support, electronics shop space, and supplies

Measurement Strategy

- Deploy vertically profiling larval-simulator drifter buoys (APEX floats) across archipelago.
- Deploy profiling AUVs to monitor repeatedly the upper ocean currents and ocean properties along archipelago.
- Deploy and rotate an array of moored ADCPs, current meters, wave monitors in nearshore/atoll environments.

Connectivity Hydrodynamics—Strategic Sampling (CH-SS)



Science Objectives

- Survey oceanic features that may play an important role in the connectivity of the archipelago.

Mission Description

- Make in-situ surveys of oceanographic features observed by remote sensing or inferred from fixed instrumentation arrays.
- Understand processes of fronts, upwelling funnels, depth stratification, etc., and how connectivity would be influenced.

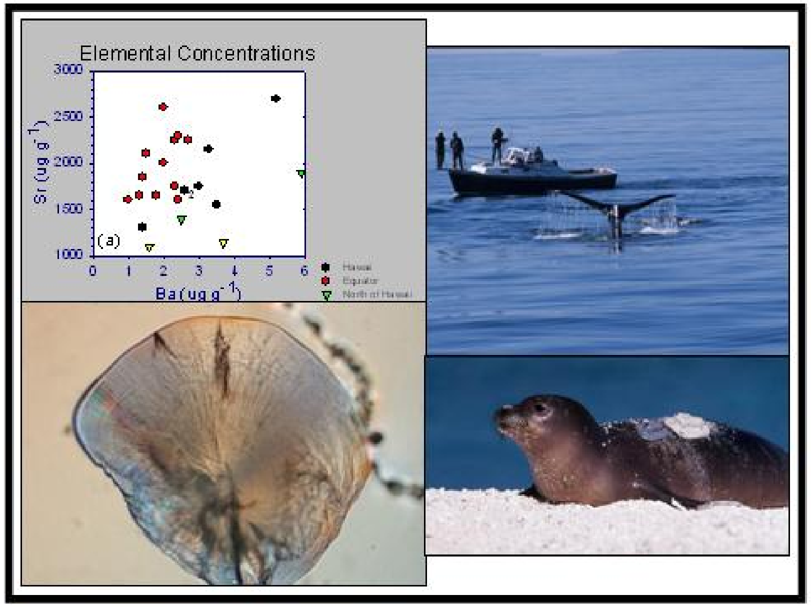
Key Infrastructure Requirements

- Data resources at NASA, JPL, NOAA, universities, and international satellite data community
- Ship time for deployment of equipment and shipboard hydrographic surveys
- Workspace for equipment construction, modification, repair, and storage
- Computing facilities for data processing, archiving, and distribution

Measurement Strategy

- Record ocean currents, ocean temperature, ocean color, and other physical and biological properties of the ocean using conventional CTD transects, drifters, etc.
- Deploy profiling AUVs to monitor upper ocean currents and ocean properties repeatedly along the archipelago.

Connectivity Movement—Marks and Tags (CM-MT)



Key Infrastructure Requirements

- Dedicated lab technician position for otolith processing
- Funding for contracted analytical chemical assays at academic laboratory (at Oregon State University)
- Funding for tagging gear and field deployments

Science Objectives

- Use natural marks (otoliths, fluke scar patterns) and tagging technology (spaghetti tags, sonic tags, satellite tags) to document range and movement within the archipelago at an ecologically relevant time frame.

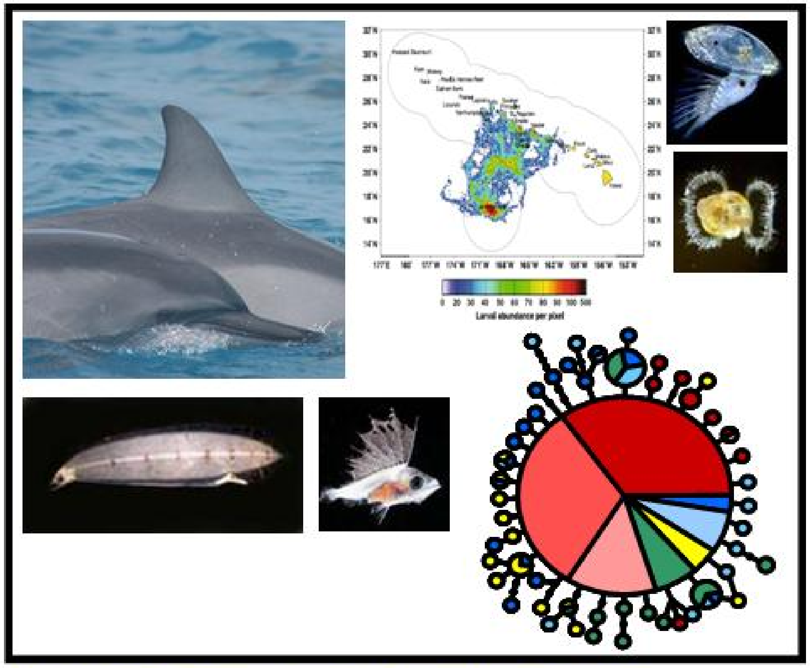
Mission Description

- Obtain chemical evidence of the spatial and temporal patterns of planktonic dispersal for key resource species of reef fishes.
- Evaluate patterns for evidence of "reseeding" within discrete reefs vs. dispersal among reefs separated by varying distances from one another throughout the archipelago.
- Deploy tags to characterize adult movements and link to environmental variables.

Measurement Strategy

- Conduct assays of otolith elemental chemistry.
- Deploy pit tags, satellite tags, and sonic tags with listening arrays.

Connectivity Population—Genetics (CP-G)



Science Objectives

- Conduct population genetic surveys of 20–30 invertebrates (including corals and lobsters) and 20–30 fishes (including commercially harvested fishes) 5–10 cetaceans (dolphins and whales).
- Quantify the scales and magnitude of isolated ecosystems in the NWHI and resolve the level of larval dispersal between the NWHI and the MHI and elsewhere.

Overall Mission Description

- Document management units throughout the archipelago, and identify biologically meaningful boundaries.
- Identify potential source populations to assign recruits and develop an empirical connectivity matrix across the archipelago.

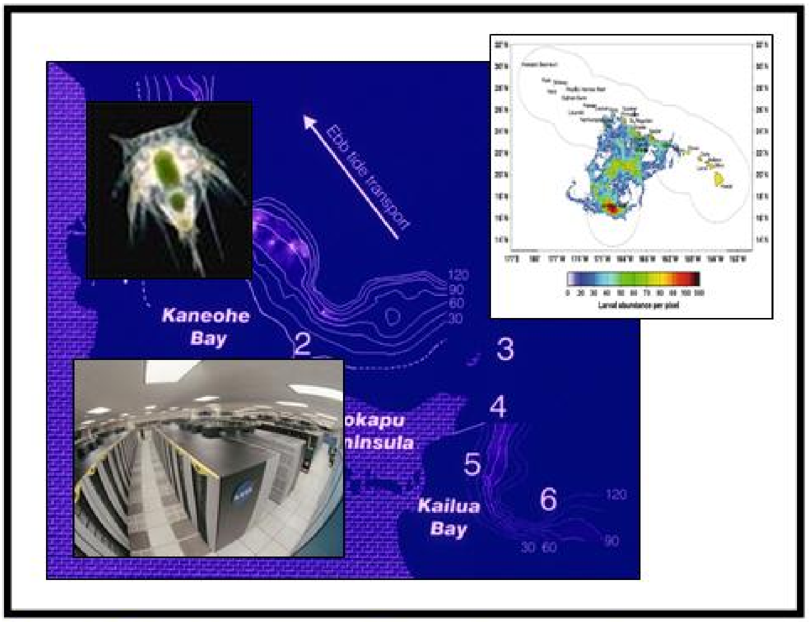
Key Infrastructure Requirements

- Access to sites throughout archipelago, including extended field expeditions to key locations
- Funding for lab-based analyses of specimens
- Coordination with prioritized research in other areas: larval recruitment, biophysical models of larval dispersal, biodiversity, oceanography, and stock assessments

Measurement Strategy

- Resolve generalized patterns of connectivity across the archipelago that correlate with life history, ecology or taxonomic affinity. Provide managers with priorities for protected areas.

Connectivity—Transport Modeling (C-TM)



Science Objectives

- Use products from other themes to model transport and connectivity throughout the archipelago with the goal of reducing in-situ monitoring demands.

Mission Description

- Define scope of modeling.
- Recruit modeling team.
- Develop and test sub-models for species groups.
- Merge sub-models.
- Ground-truth and tune model.

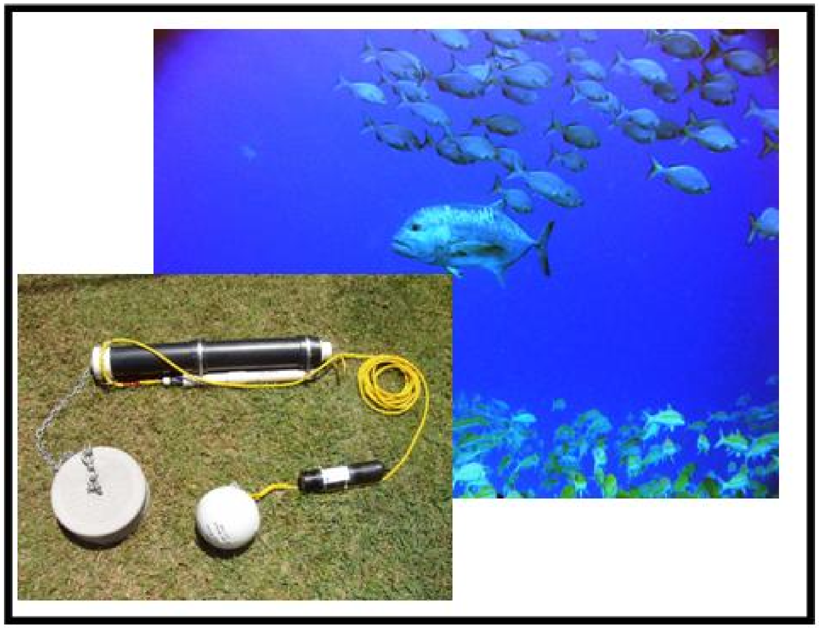
Key Infrastructure Requirements

- Tightly focused research consortium to develop modeling pieces and complete successful merger
- Supercomputer for model development and runs
- Routine computing facilities for data processing, archiving, and distribution

Measurement Strategy

- Investigate currents and other physical properties of the ocean to estimate biological parameters as they pertain to connectivity.

Human Interactions—Catch and Release (H-CR)



Science Objectives

- Determine the impact of catch and release fisheries.
- Support studies on the home range of animals.

Mission Description

- Determine the impact of catch-and-release fisheries on fish behavior and movement patterns in the Hawaiian Islands.

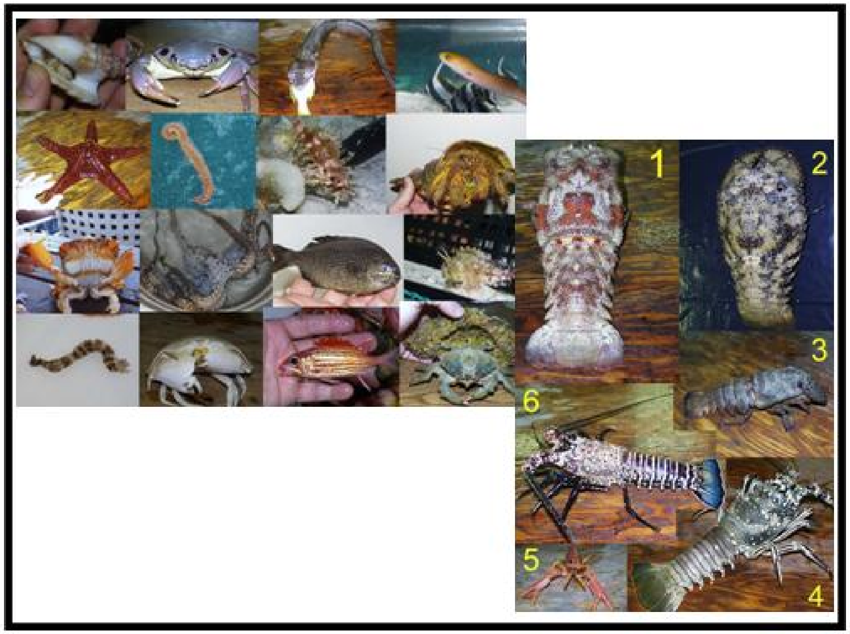
Key Infrastructure Requirements

- Fishing gear, tagging gear, acoustic tags, listening stations, and diving gear
- Purchasing or support for farm raised fish
- Funding for contract staff associated with fishing, tagging, raising of fish and diving.

Measurement Strategy

- Tagging and acoustic tracking; determine the survivability of fish after being recreationally caught and released.

Human Interactions—Ecosystem Shift (H-ES)



Science Objectives

- Evaluate temporal changes in abundance and diversity in trappable faunal communities.
- Monitor the recovery of the spiny lobster population and its dynamic relationship with slipper lobster populations at a once heavily fished bank in the NWHI.

Mission Description

- Continue a 20+ year time series of site specific lobster trapping operations.
- Analyze changes in community diversity and relative abundance of all captured species.

Key Infrastructure Requirements

- Standard lobster traps and a vessel with trap hauling capabilities
- Funding for staff associated with such field and laboratory activities

Measurement Strategy

- Conduct site specific lobster trapping operations.
- Identify and enumerate all captured organisms.
- Record size and reproductive information on all captured lobster.

Human Interactions—Retrospective Analysis (H-HIS)

Science Objectives

- Understand the trends of human activities associated with the ecosystem.
- Estimate the economic value of various human activities related to the ecosystem.

Mission description

- Analyze the attributes of use value and nonuse value of various human activities to the ecosystem (living marine resources).
- Monitor and predict changes of the associated human activities and the value to the ecosystem of key elements.

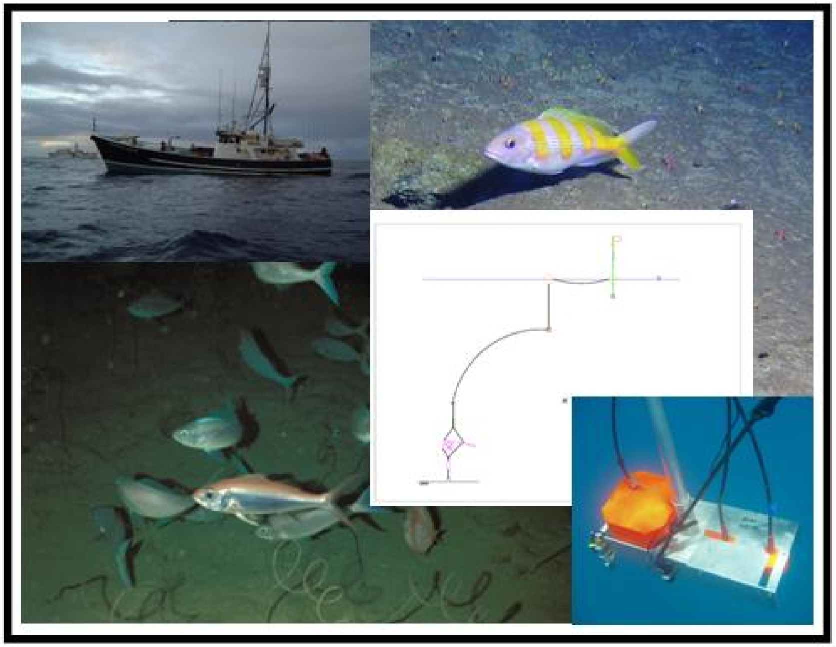
Key Infrastructure requirements

- Funding for a contract staff
- Office space

Measurement strategy

- Develop measurements to valuate various human activities/interactions and their value to ecosystem.
- Establish mechanism to predict/monitor the changes of various human activities/interactions.

Human Interactions—Implementing Restoration (H-IR)



Science Objectives

- Evaluate the effects of marine protected areas (MPAs) on stocks of commercial species and their associated faunal communities.
- Evaluate socioeconomic impacts of MPAs on fishing communities.
- Increase stakeholder understanding and participation in applied marine research.

Mission Description

- Compare the relative biomass of various species between closed and open fishing areas.
- Analyze changes in participation and profitability with the implementation of MPAs.
- Determine if MPAs displace fishing pressure.

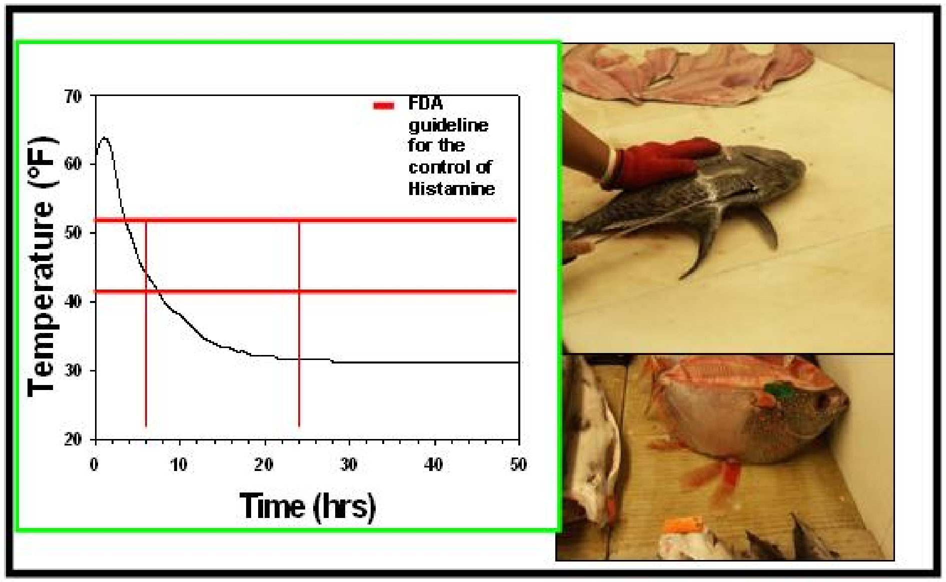
Key Infrastructure Requirements

- Gear to access resource abundance within and outside of MPAs (drop cameras, deep ROVs and submersibles, vessels with trapping and fishing capabilities)
- Funding for contract staff associated with such field and laboratory activities
- Funding for interagency research survey workshops

Measurement Strategy

- Conduct a biannual, stratified random sampling of selected communities both within and outside of MPAs.
- Collect information using multiple sampling gears—fish traps, BOTCAM, longline, CTD, hydroacoustics.
- Survey fishers to collect participation and economic information.

Human Interactions—Seafood Safety and Stocking Enhancement (H-SSSE)



Science Objectives

- Conduct seafood safety investigations.
- Conduct seafood quality improvements.
- Conduct research associated with cage culture and stocking programs.

Mission Description

- Identify seafood-related public health problems.
- Conduct research to assist safety and quality improvements.
- Provide expertise to other federal and state agencies.
- Look for impacts and ecological effects of cage cultures/stocking programs.

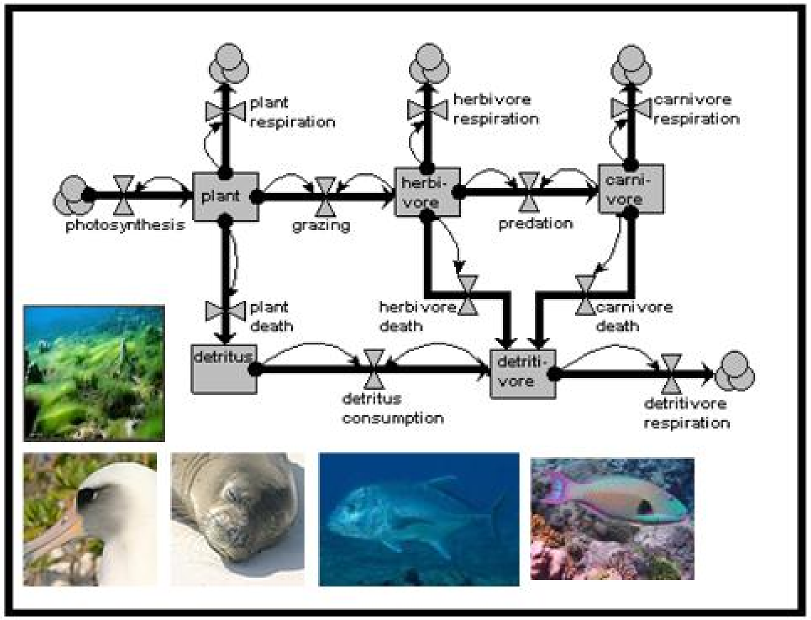
Key Infrastructure Requirements

- Contracted vessel time: documentation of fishing methods and post harvest handling methods
- Contracted laboratory assays
- Funding for contract staff associated with seafood safety projects

Measurement Strategy

- Augment monitoring programs where needed.
- Conduct training workshops.
- Conduct assessments of cage culture facilities.

Resilience—Energy Flow (R-EF)



Key Infrastructure Requirements

- Gear to conduct surveys (diving equipment)
- Research vessel time
- Collection gear (e.g., specimen suction vacuums, specialized traps etc.)
- Funding for contract staff associated with such surveys and modeling

Science Objectives

- Quantify the role energy flow in ecosystem recovery.

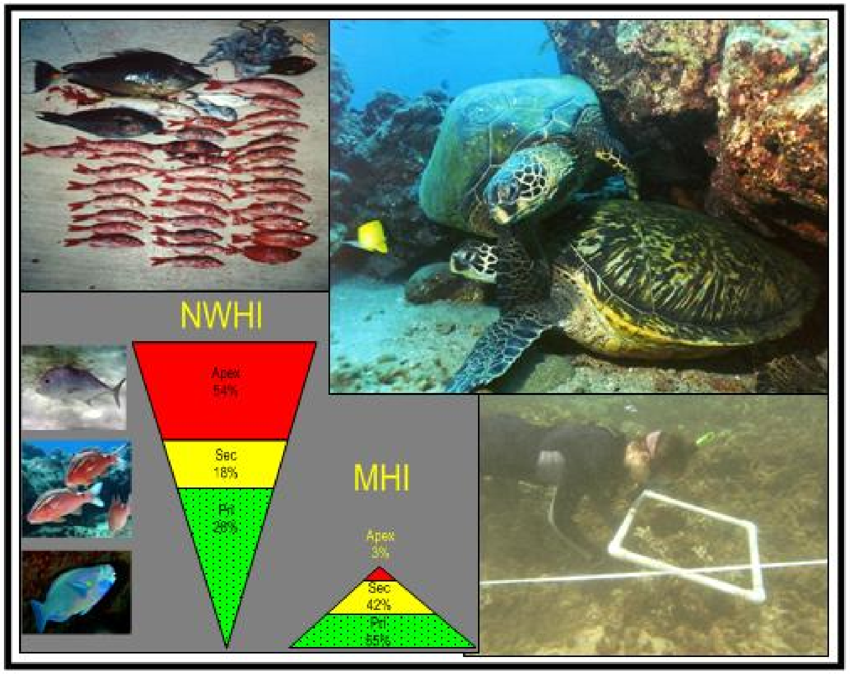
Mission Description

- Conduct baseline surveys to estimate abundance/biomass of index species representing different habitats and trophic levels.
- Determine diet and trophic interactions using stomach contents, fatty acids, and other techniques to determine energy flow between trophic levels.
- Incorporate oceanographic and other data to determine how they impact energy flow to apex predators, in particular endangered Hawaiian monk seals.

Measurement Strategy

- Conduct a series of regional expeditions focused on specific ecological subsystems. (Atoll, slope, subphotic, pelagic, etc.). Most can be conducted in coordination with other programs.
- Monitor species and prioritize expeditions relative to management need and efficiency in logistics.

Resilience—Fishing Impacts (R-FI)



Key Infrastructure Requirements

- Research expansion into recruitment, mortality, trophic, and age structure
- Synthesis of existing work to develop priority areas for expanded research
- Funding for contract staff associated with strategic sampling surveys

Science Objectives

- To what degree does removals impact ecosystem resilience?
- What sustains high levels of predator abundance if turnover is low?
- How does fishing impact the trophic web?

Mission Description

- Understand the ecological impacts of natural variability and variability associated with extraction.
- Understand population dynamics (recruitment, mortality, age, and growth) of unfished NWHI and along a gradient of fishing in the MHI.
- Determine prerequisites needed for a fish resource to recover.

Measurement Strategy

- Measure variability in adult populations, juvenile survival, and recruitment dynamics of natural and fished systems.
- Examine age, size, and trophic of the unfished NWHI and areas along a gradient of fishing impacts in the MHI.
- Look for interspecific competition associated with recovery from fishing.

Resilience—Natural Variability/ Disturbance (R-NV/Dist)

Science Objectives

- Develop reliable model—based on community and ecosystem changes—as a function of natural variability and disturbance dynamics.
- Fill information gaps and identify additional biologically relevant metrics to quantify and model ecosystem change.

Mission Description

- Evaluate the role of natural variability in coral ecosystem resilience and recovery.
- Develop an understanding of the regional consequences of climate change based on ecosystem variability and disturbance regime.

Key Infrastructure Requirements

- Structured coordination with research prioritized in other themes
- Funding for contract staff associated with field-laboratory research and modeling
- Funding for periodic workshops and reviews

Measurement Strategy

- Do a metrics of community structure, energetics, and nutrient cycling.
- Conduct general system level trends.

Resilience—Physical Environment (R-PE)

Science Objectives

- Identify pathways for ecosystem resilience to environmental change.
- Predict terrestrial ecosystem response to natural and anthropogenic change.
- Develop mitigation measures to maintain habitats and biodiversity.

Mission Description

- Map current NWHI terrestrial habitats (high resolution elevation data).
- Regularly repeat measurements to evaluate changes in habitats over time.
- Model shoreline evolution under higher sea level and model mitigating measures (beach nourishment).

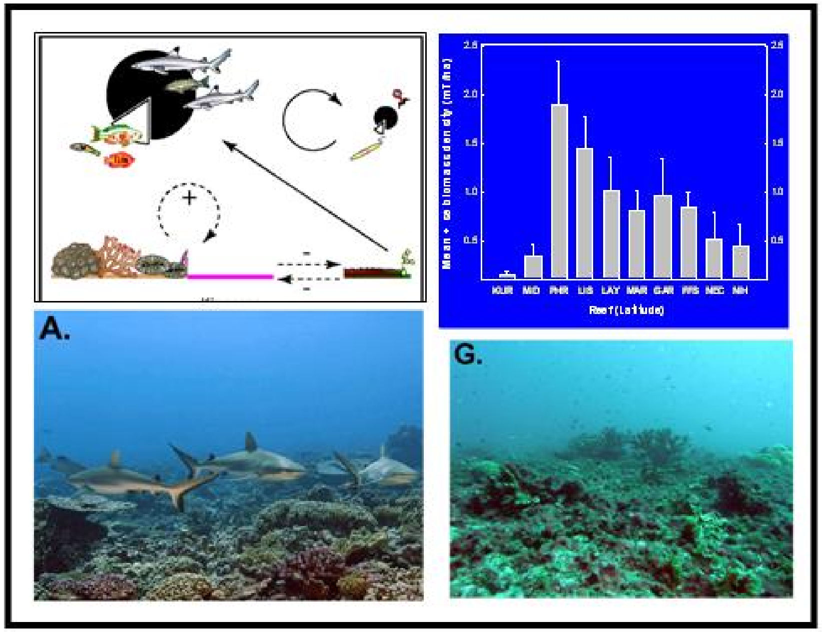
Key Infrastructure Requirements

- Funding for LIDAR surveys, support for modeler, workshops to develop mitigation scenarios
- Structured coordination with research prioritized in other themes

Measurement Strategy

- Conduct LIDAR surveys to obtain high resolution elevation and bathymetry data for NWHI.
- Regularly resurvey (every 3 yrs) with LIDAR to monitor changes.
- Analyze all existing photographic records to evaluate past changes to terrestrial habitats to date.

Forecasting—Community Structure (F-CS)



Science Objectives

- Develop metrics of assemblage structure (e.g., piscivore-to-herbivore ratios, size structure within trophic levels) that describe biotic communities and capture the process of community function.
- Conduct periodic surveys and analyses to evaluate the temporal dynamics of these metrics.

Mission Description

- Establish a synoptic baseline characterization for the entire Hawaiian Archipelago (NWHI plus MHI); repeat for temporal component.
- Make recommendations to the managers who are developing measures of ecosystem-based fisheries management.

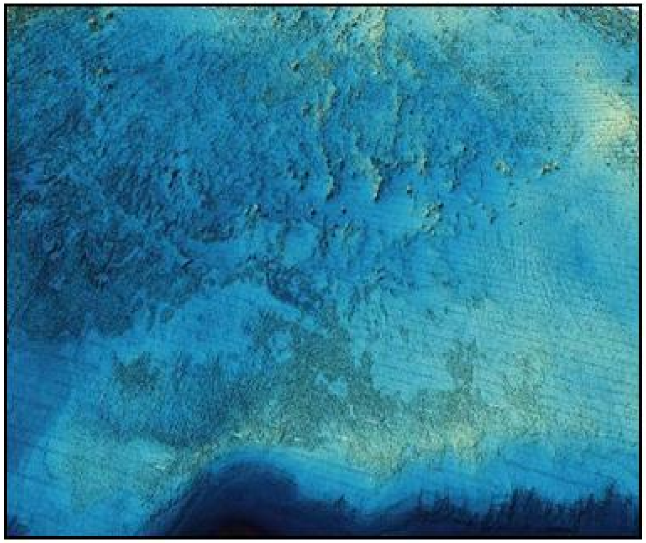
Key Infrastructure Requirements

- Responsibility for research as well as habitat and resource protection shared among NWHI-MNM co-trustees
- Coordination between PIC researchers and NWHI-MNM cotrustees and contractors
- Coordination of allied PIC (FBSAD, EOD) researchers and existing CRED monitoring program and personnel and PIC cruises

Measurement Strategy

- Examine community structure under top-down and bottom-up control.
- Periodically reassess (every 4 yr) by involving collaboration of several empiricists and modelers.

Modeling and Forecasting—Habitat Mapping (F-Map)



Science Objectives

- Collect and disseminate appropriate types of data to serve as baseline habitat information for ecosystem-based management.
- Develop methodologies whereby changes in habitat can be identified and modeled using mapping data.

Mission Description

- Identify methodologies that are most appropriate and cost-effective for use in specific areas and depth ranges.
- Collect appropriate data across Hawaiian Archipelago.
- Develop automated and standardized techniques for integration of multiple data types into consistent benthic habitat maps.

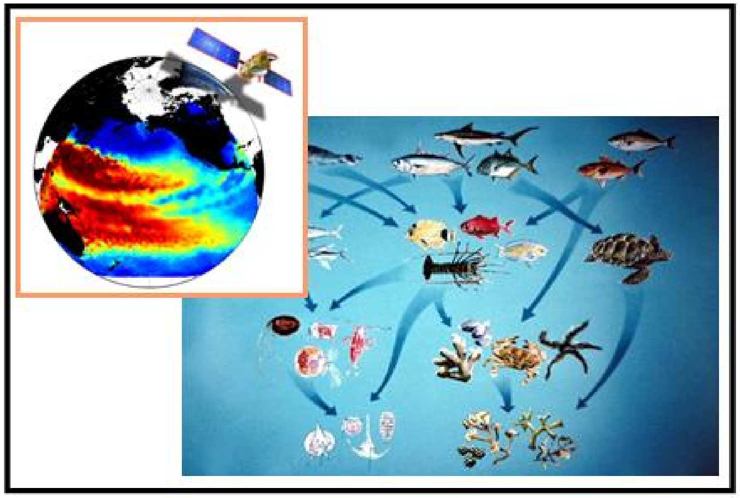
Infrastructure Requirements

- Access to ships and launches with multibeam sonars and optical data collection capabilities
- Funding for satellite and aerial surveys as appropriate
- Infrastructure for processing, integrating and analyzing multiple data types that are required for comprehensive habitat maps

Measurement Strategy

- Plan regional expeditions to collect baseline data needed for habitat maps.
- Coordinate multiagency strategies for collecting satellite and/or aerial data.
- Support regional mapping center for data analysis and processing.

Forecasting—Model Quality Control (F-MQC)



Science Objectives

- Verify or reject the viability of model components.

Mission Description

- Identify gaps and point of uncertainty in the models.
- Design studies to test assumed relationships.

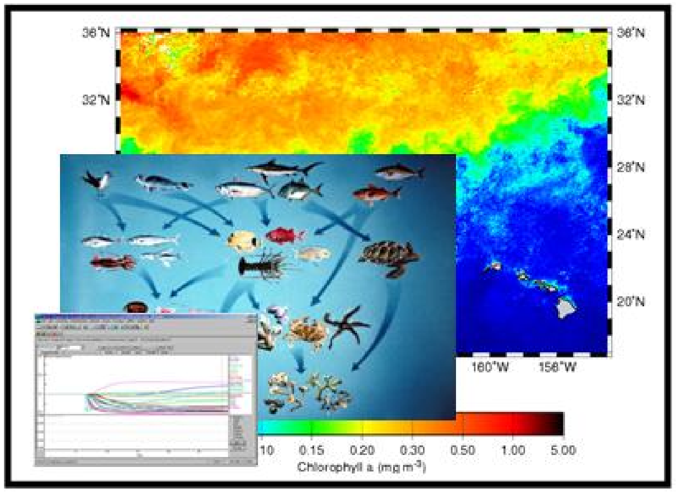
Key Infrastructure Requirements

- Funds for field studies conducting validation research using the available research infrastructure as prioritized in other themes
- Funds for collaborators to travel and assist with studies that require specialized expertise

Measurement Strategy

- Assess the degree of agreement between field studies and model output.
- Reconfirm parameters that appear to play key roles in the model's performance.

Modeling and Forecasting (F-Predict)



Science Objectives

- Predict (probability scenarios) ecosystem response to natural and anthropogenic change.
- Project feedback to ecosystem reproduction, transport, and carrying capacity.

Mission Description

- Make projections for established ecosystem indicators.
- Continue evaluation of results to estimate and refine predictive resolution.

Key Infrastructure Requirements

- Structured coordination with research prioritized in other themes
- Funding for modeling staff to conduct ECOPATH/ECOSIM ATLANTIS type analyses
- Funding for periodic workshops and reviews to evaluation model performance

Measurement Strategy

- Expect annual or seasonal fluctuations based on physical conditions.
- Track energy flow/impact ripples through the ecosystem over multiple years.

Availability of NOAA Technical Memorandum NMFS

Copies of this and other documents in the NOAA Technical Memorandum NMFS series issued by the Pacific Islands Fisheries Science Center are available online at the PIFSC Web site http://www.pifsc.noaa.gov in PDF format. In addition, this series and a wide range of other NOAA documents are available in various formats from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, U.S.A. [Tel: (703)-605-6000]; URL: http://www.ntis.gov. A fee may be charged.

Recent issues of NOAA Technical Memorandum NMFS–PIFSC are listed below:

NOAA-TM-NMFS-PIFSC-8 Hawaii longline fishermen's experiences with the observer program.
S. STEWART and A. GOUGH
(February 2007)

9 The Hawaiian monk seal in the Northwestern Hawaiian Islands, 2003.
T. C. JOHANOS and J. D. BAKER (comps. and eds.)
(March 2007)

10 Chemoreception in loggerhead sea turtles: an assessment of the feasibility of using chemical deterrents to prevent sea turtle interactions with longline fishing gear.
A. SOUTHWOOD, B. HIGGINS, and Y. SWIMMER
(July 2007)

11 Linking Hawaii fisherman reported commercial bottomfish catch data to potential bottomfish habitat and proposed restricted fishing, areas using GIS and spatial analysis.
M. PARKE
(September 2007)

12 2006 Sea turtle and pelagic fish sensory physiology workshop, September 12-13, 2006.
A. SWIMMER and J. H. WANG (comps. and eds.)
(October 2007)

13 Corrected catch histories and logbook accuracy for billfishes (Istiophoridae) in the Hawaii-based longline fishery.
W. WALSH, K. BIGELOW, and R. ITO
(December 2007)